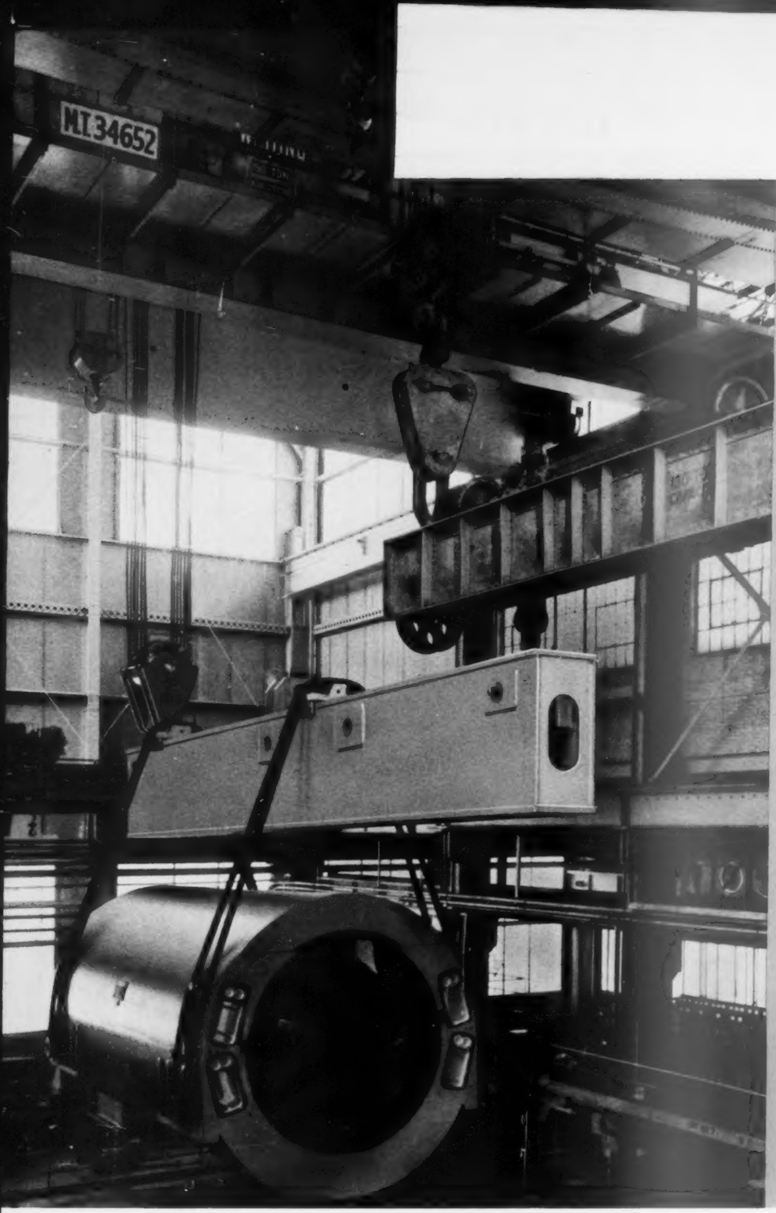
ALLIS-CHALMERS Electrical REVIEW

4TH QUARTER 1961



A 150 ton generator stator being moved at West Allis Works. This demonstrates one small part of the capability of Allis-Chalmers manufacturing facilities where skilled craftsmen in careful quality controlled production processes turn out a broad line of processing, fluid-handling, power and electrical equipment. The close cooperation among design, application and manufacturing personnel assures the purchaser of fast, efficient production in accordance with a uniform set of quality standards.

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...A trademark
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Overseas operations are conducted by ALLIS-CHALMERS INTERNATIONAL through its world-wide distributor organization. The distributor in your country is ready to give you as much help as you want or need. He is backed up by competent, local Allis-Chalmers International representatives who draw upon the firm's engineering, research and testing facilities. He will work with your engineers or consultants to determine the most profitable equipment for your operation.

In power houses throughout the world, Allis-Chalmers steam and hydraulic turbines drive Allis-Chalmers generators. The electricity generated is controlled and sent on its way through A-C switchgear and transformers. Also, in the field of nuclear power, A-C training, research and test reactors and several types of power reactors have been built, or are now being built.

ALLIS-CHALMERS Electrical REVIEW

THE COVER

TUSCARORA PLANT of New York State Power Authority's Niagara Power Project will be in full operation in 1962. Three of the 12 pump-turbine units, each rated 37,500 hp as a pump and 28,000 hp as a turbine driving its motor as a generator, are already in operation. The combined output of the plant will be greater than any other pump-turbine plant in the world.

Photo courtesy of Power Authority of the State of New York

Allis-Chalmers

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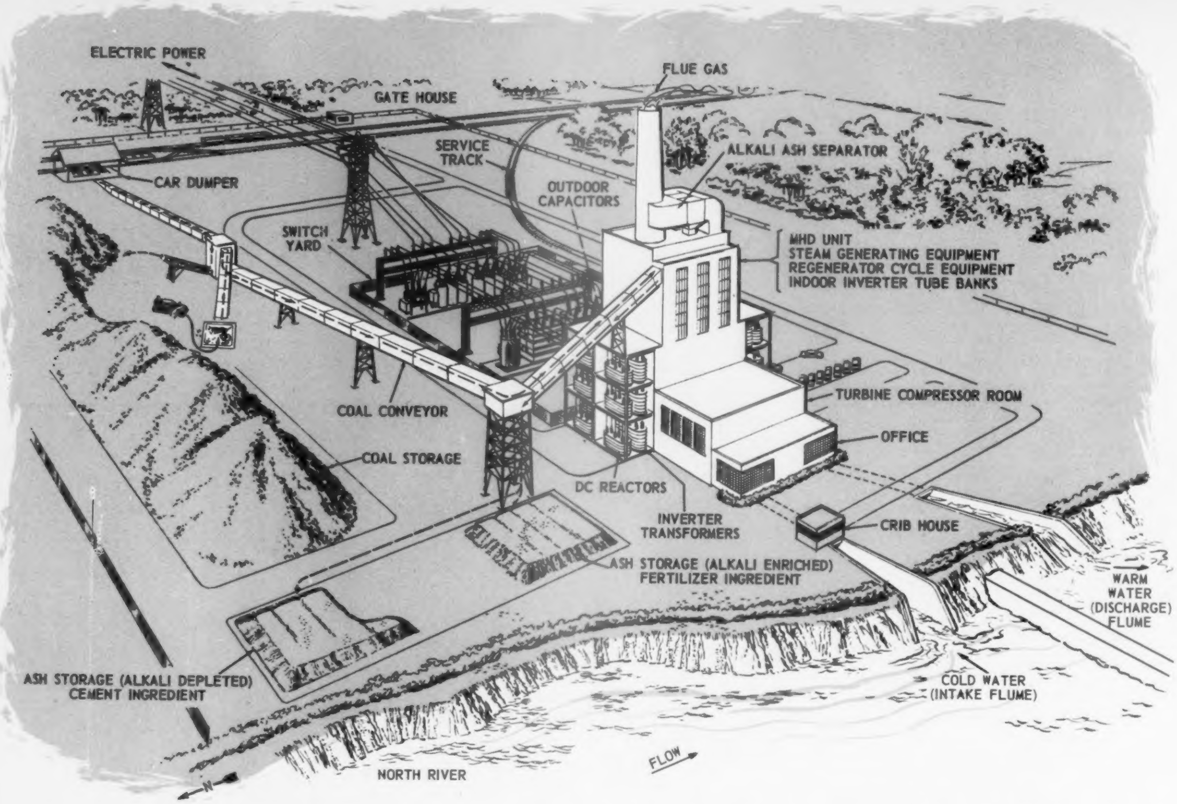


DIRECT ENERGY CONVERSION WITH MHD

MAGNETOHYDRODYNAMIC POWER PLANT envisioned for generating 300 mwe was subject of detailed design and computer study by Allis-Chalmers Manufacturing Company with The Babcock & Wilcox Company and Sargent & Lundy Engineers, Combustion and Explosives Research, Inc., and MHD Research Inc. All aspects of the plant were evaluated and the overall operation compared to a conventional steam plant. **(FIGURE 1)**

EDWARD F. BRILL
Consulting Engineer
Allis-Chalmers Mfg. Co.

Electric power, obtained directly from plasma flowing through a strong magnetic field, is aim of new developments.

Plasma, an ionized gas or vapor, is an electrical conductor which can be used to produce electricity in a magnetohydrodynamic, MHD, generator. An MHD plant envisioned for the future is shown in Figure 1.

When heat is applied to atoms or molecules of a gas, a certain number of atoms will be ionized, and if the temperature is increased, more atoms will ionize. At low temperatures, the atoms of a gas are neutral atoms, and the number of positive charges in the nucleus equals the number of negative charges of the electrons orbiting the nucleus. As heat is applied and temperature increases, the electrons of some atoms leave their orbits and in doing so, these atoms become positive ions with the release of electrons which are negatively charged particles.

Therefore, at elevated temperatures the ionized gas contains a number of neutral atoms, positive ions and negative electrons. This mixture is electrically conductive. The degree of ionization and the conductivity of the gas naturally increase as more atoms ionize.

The heat from the fuel burned in a combustion chamber heats the gas to a plasma state. The plasma is accelerated, as shown in Figure 2, by means of a nozzle to a high velocity and is passed through a magnetic field at approximately 2000 miles per hour. This plasma flow through the magnetic field would generate a voltage of between 1000 and 3000 dc volts in an MHD generator such as shown in Figures 3 and 4.

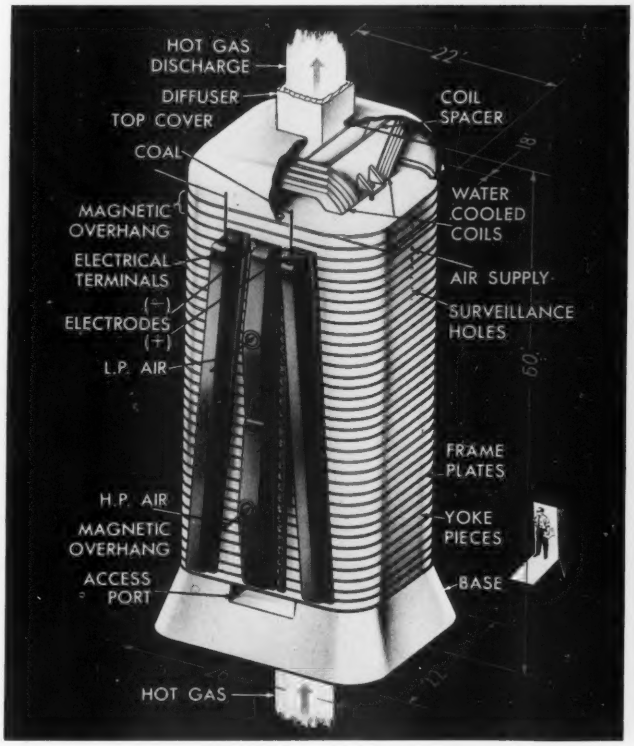
Gas expands as it travels through the flow channel. The flow channel rests between the faces of the magnet, and has side collectors for conducting electricity. The expansion and corresponding drop in gas temperature is similar to that which is encountered in a gas turbine operating between the inlet and outlet pressure. Gas would leave the MHD generator at a temperature high enough to retain a high degree of ionization or approximately 4000 F.

Seeding adds to efficiency

By injecting an ionizing additive, seeding, the energy required to ionize the gas is greatly reduced and the electrical conductivity of the gas increased. The length of the generator for a given power output is inversely proportional to the conductivity and if the conductivity is increased sufficiently, the field strength can be reduced, excitation losses lessened and the coil construction simplified.

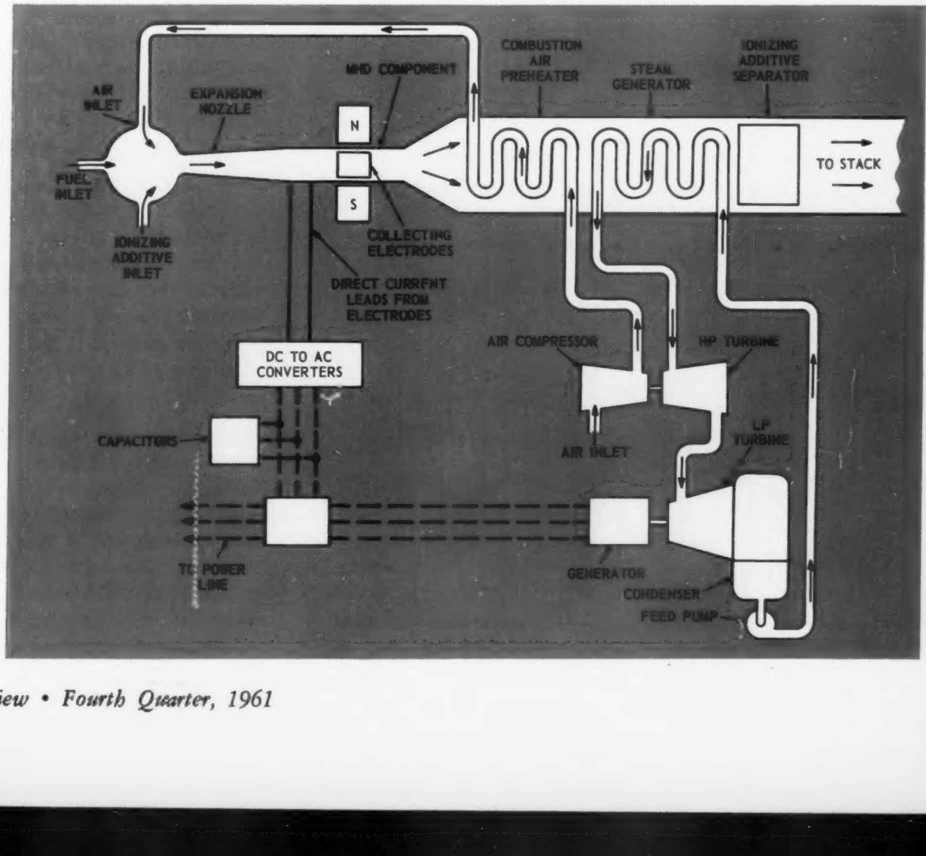
The most important consideration in the selection of a seed material is cost. A study on seeding materials for a large coal fired MHD power plant indicated that seed requirements of the cycle can be met by the alkali content in coal. This seed alkali is recirculated. If the potassium or alkali content of the fuel is greater than the losses of the system, additional revenue can be expected by marketing the excess seed material as fertilizer. Cesium could be used as a seed material and would greatly increase the conductivity but because of its correspondingly higher cost a closed or recirculating cycle would be necessary. The flow chart of Figure 5 shows one seeding method using the seed material found in the coal.

To produce temperatures of about 5000 F exhausting from the MHD nozzle air must be preheated. As air is heated to high temperatures, dissociation and ionization occur which absorb heat energy. If air is injected into a fuel chamber at 80 F, the exhausting gases of burning coal are about 3000 F, but if the air is preheated to 3800 F, the exhaust gases reach a temperature of about 5000 F. In the first case, in the lower ranges of tempera-



MHD GENERATOR design calls for vertical column of high velocity ionized gas passing through a strong horizontal magnetic field and discharging at the top. Direct current generated across the hot gas is collected by a series of electrodes along the path of the gas at the front and rear of the generator. **(FIGURE 3)**

MHD AIR-STEAM CYCLE would supply preheated air to the combustion chamber where gas is heated to plasma state. High temperature gas exhausted from MHD generator component preheats the air and also generates steam for high pressure turbine driving the compressor. Power from low pressure turbine drives generator supplying added power to the system. **(FIGURE 2)**

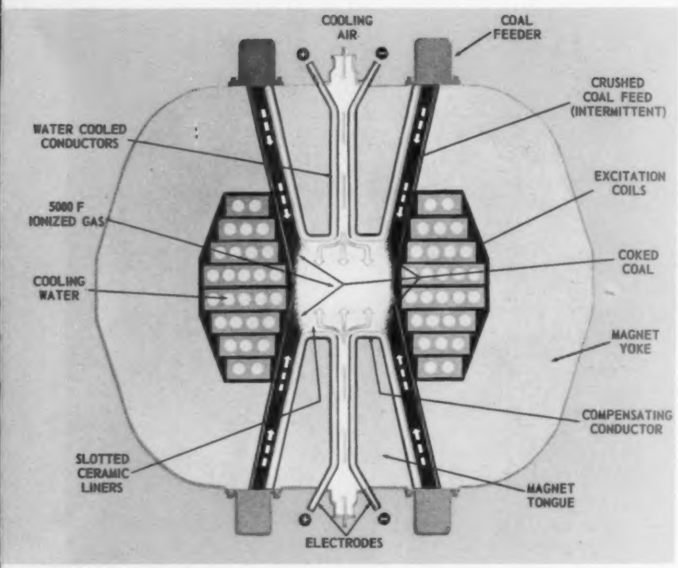


ture, the fuel heated the air approximately 3000 F whereas in the higher ranges of air-preheat-temperature, the fuel heated the air only 1200 F.

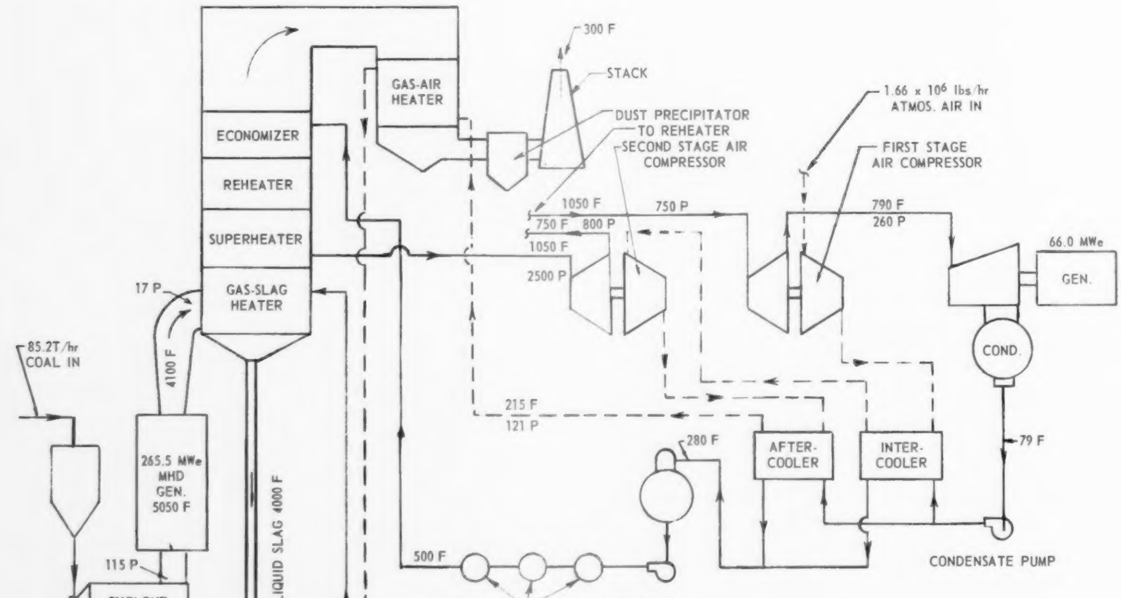
In MHD, the air is preheated by means of a regenerator, as shown in Figure 5. The regenerator transfers heat from the gases leaving the MHD power generator to the incoming air. This regenerator is an extremely important part of the MHD power cycle shown in Figure 6. As the temperature difference between the gases leaving the MHD power generator and air going into the combustion chamber becomes smaller, the cycle becomes more efficient.

To improve cycle efficiency, designers place a diffuser between the discharge side of the generator and the regenerator. This slows the gases and converts some of the kinetic energy into pressure. The temperature of the exhausting gases is therefore increased, thereby producing a higher gas temperature entering the regenerator for the transfer of heat to the incoming air stream.

In an MHD power plant the flue gases leaving the regenerator are at high temperatures and considerable energy can be extracted from the flue gas by using a conventional steam power plant cycle to recover this waste heat. Steam could first be used to drive a turbine-compressor which will force compressed air through the preheater for injection into the combustion chamber. The remaining energy in the steam can be extracted by passing it through a conventional turbine-generator.



MHD GENERATOR CROSS SECTION shows electrode and magnet design. Consumable electrodes consist of coke produced by heating coal as it is forced through the electrode chutes. **(FIGURE 4)**



REGENERATOR SYSTEM, incorporating features suggested by The Babcock & Wilcox Company, brings gas entering the MHD cyclone type combustion chamber to 3800 F using exhaust heat and a liquid slag heat transfer cycle. **(FIGURE 5)**

The MHD generator develops direct current. It is necessary that this be inverted to alternating current for transmission over power lines. In a power plant of roughly 300,000 kw, approximately 80 percent of the total electrical power could be developed by the MHD generator and 20 percent by the turbo-alternator. Electrical power can be extracted from the high temperature flue gases in the MHD generator at efficiencies of 80 percent or better, thereby leaving less power to be extracted from the gases in the conventional steam cycle at 40 percent efficiencies. In a combined cycle, it appears possible to obtain efficiencies of 57 percent with an open cycle burning coal.

Nuclear MHD cycle possible

A closed cycle using nuclear energy could permit efficiencies approaching 60 percent. A gas such as helium can be circulated in a closed loop through a nuclear reactor. In this cycle, there would be no loss of radioactive materials to the atmosphere. Essentially, the combustion chamber is replaced by the nuclear reactor which heats helium as it passes through the reactor. Ionization occurs in helium gas at lower temperatures and higher gas velocities are possible.

Economy gained with higher ratings

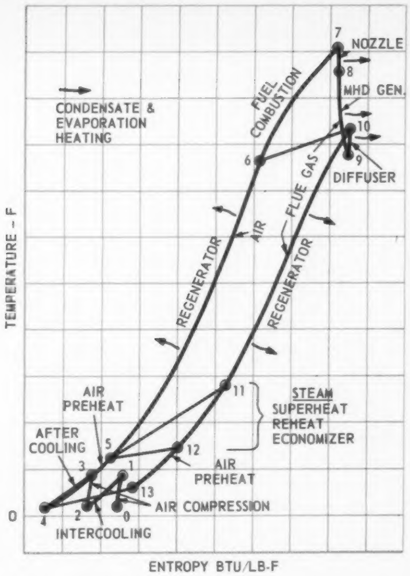
It is generally known that the efficiency of power converting machines or equipment increase with size. The curves of Figure 7 show the calculated performance of various sizes of MHD plants.

Plant maintenance and operating cost per kwh output decreases as the plant size goes up. The total production cost decreases as MHD plant ratings increase. These cost trends are shown in the curves of Figure 8.

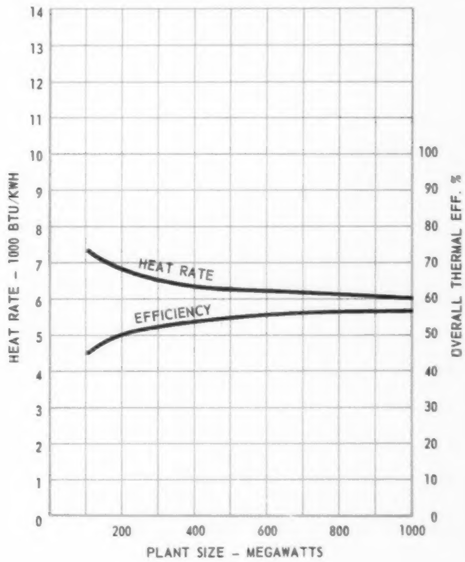
While present designs have been based on a direct current generator, three methods have been considered for generating alternating current. These are pulsing the plasma flow, pulsing the field and pulsing the conductivity of the plasma. At present these arrangements do not seem practical for generating large blocks of power.

Magnetohydrodynamics has offered an exciting challenge to engineers for producing large blocks of electrical power from ionized gases, but there are a number of problems unsolved. Some of these are containment of high temperature and high velocity gases, reduction in Hall and end effects of the generator, and the development of regenerators and diffusers. The solutions to these problems will spur the growth of plasma as an engineering medium in many related fields.

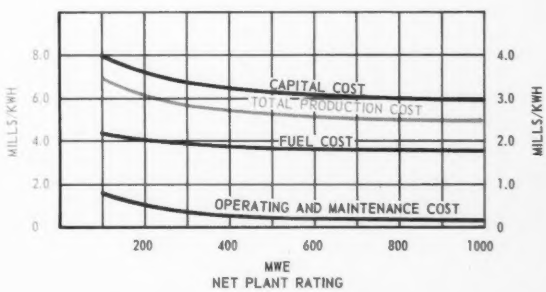
An exhaustive study comparing operating costs of the MHD generating system with a conventional steam plant showed the conventional power plant to be somewhat more economical than the MHD plant. In this study higher contingencies were used because of the development aspects of MHD. The capital cost estimates of the plant were higher than conventional plants. MHD has a future, however, if capital costs can be reduced or if fuel costs rise more rapidly than price levels of capital equipment. ◆



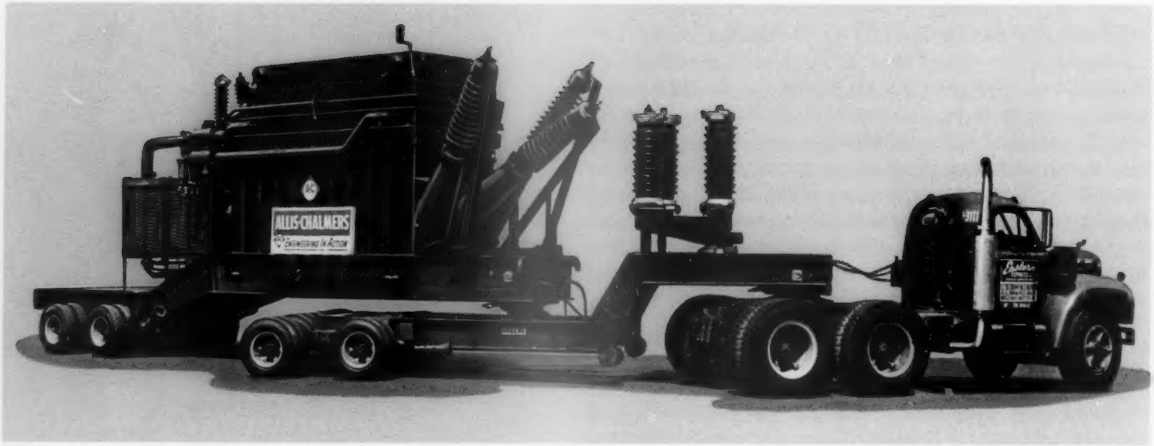
MHD POWER CYCLE shows importance of heat recovery systems. One, exhaust gas to incoming air; the other, using condensate water to cool the high temperature parts and compressed air. **(FIGURE 6)**



MHD PERFORMANCE, T_{MAX} of 5050 F and P_{MAX} of 8.45 ATM **(FIG. 7)**



COST for MHD PLANTS are based on 14 percent depreciation per year, 80 percent load factor and 30 cents per 10^6Btu. **(FIGURE 8)**



EMERGENCY, maintenance or construction are uses for mobile transformers. This 20,000-kva unit will serve West Coast area. **(FIGURE 1)**

POWER ON WHEELS

L. W. SCHOENIG
Transformer Department
and
J. V. BONUCCHI
Terre Haute Works
Allis-Chalmers Mfg. Co.

Large mobile transformers and substations assure improved service continuity with less equipment cost.

ADDITIONAL TRANSFORMER CAPACITY is frequently provided by spare units or units which are not loaded to capacity and is, therefore, available when required. To insure service with a minimum of down time, this reserve capacity must be available at each substation or distribution point. The disadvantage of providing reserve transformer capacity in this manner, although it does insure continuity of service, is the relatively high equipment cost.

This reserve capacity can be supplied with less equipment cost by mobile transformers, such as shown in Figure 1, or by mobile substations. One mobile unit can be used to provide the necessary spare capacity for a number of substations. A large West Coast utility plans to use 40-mva single-phase mobile transformers to provide emergency spare capacity for approximately 85 transformers which are installed at 19 different locations. The mobility of these portable units permits rapid movement to the location where they may be required. One of these 40-mva units is shown in Figure 2.

Mobile spare units frequently permit release of reserve units which are permanently located at the various substations. Three-phase or single-phase reserve unit can be used as added capacity in overloaded substations or as initial capacity in new substations. The value of the reserve transformer capacity released for active use often exceeds the cost of a mobile unit.

Mobile units serve three functions

1. *Emergency* — A mobile unit may be used to replace a transformer which is damaged and can provide continuity of service until the damaged unit is repaired or replaced.

2. *Maintenance* — A mobile unit can replace an existing unit which is to be removed from service for cleaning, inspection, or overhaul.

3. *Construction* — Mobile units can be used to supply power during the early stages of project construction until the permanent power supply or substations is completed. They are also frequently used to provide service while a substation is modified or rebuilt.

Although most mobile units are obtained primarily for use in emergencies, they are more frequently used during construction or maintenance than for the purpose originally intended. Surveys have indicated that some systems use mobile units only six percent of the time for emergencies, 24 percent of the time for maintenance and 70 percent of the time for construction.

Because of limitations imposed by the State Highway commissions, mobile units must be designed to meet the applicable highway codes. These codes specify height, width, length, weight, and axle loading. Because of non-uniformity in state highway codes, it is necessary to know the area in which the mobile unit will be used to insure that it complies with the applicable codes. Generally these limitations restrict transformer capacity to 20 to 25 mva, three phase or 40 to 50 mva, single phase.

A 20-mva mobile transformer is shown in Figure 1. It is a three-phase, Type FOA, 115 to 34.5 unit and is designed to operate in parallel with 12 existing banks of transformers. The weight, dimensions, and axle loading are well within the highway limitations.

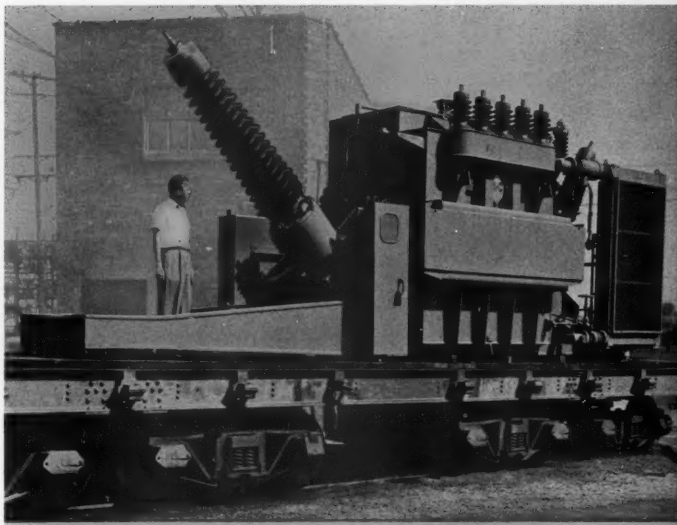
A completely self-contained substation can be mounted on wheels. Figure 3 shows such a unit. It is a 7500-kva, 43.8-kv, three-phase unit with the low voltage designed for operation at 13,090 or 4360 volts. The substation is complete with a high voltage disconnect switch, arrestors and fuses, and with low voltage arrestors and feeder breaker. In addition, a power supply and equipment for metering and relay protection are included. The use of a completely self-contained mobile substation permits by-passing a complete substation for planned maintenance, system changes, or emergencies. These units can be obtained in ratings up to approximately 20 mva.

Units designed for flexibility

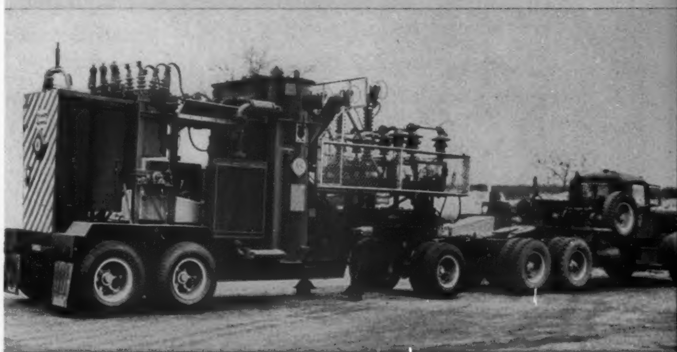
Usually mobile units are designed with a multiplicity of voltages for greater flexibility. This permits the transformer to be used as a replacement for a greater number of existing units. As an example, the high voltage winding may be arranged for 115-kv or 66-kv operation while the low voltage winding may be designed for 13.8, 13.2, 12.47, 7.2, 4.16 and 2.4 kv. This arrangement complicates the design and construction, requires tap changers or terminal boards, and affects weights and dimensions. Frequently the complexity of winding arrangement has a greater effect on size, weight and cost than kva capacity. It is desirable therefore to limit the number of voltages of the mobile unit to only those actually required for good system operation.

A typical mobile substation with a complex voltage arrangement is shown in Figure 4. It is a 10,000-kva, three-phase unit with a high voltage rating of 43,800 or 67,000 volts connected for delta operation. The low voltage rating is 2520 or 7560 volts when connected delta and 4360 or 13,090 volts when connected wye. The series multiple rating of both the high voltage and low voltage winding is accomplished by switches which are mounted under oil in the transformer tank and operated by externally mounted handles. The delta-wye transformation is made outside the tank at the low voltage bushings.

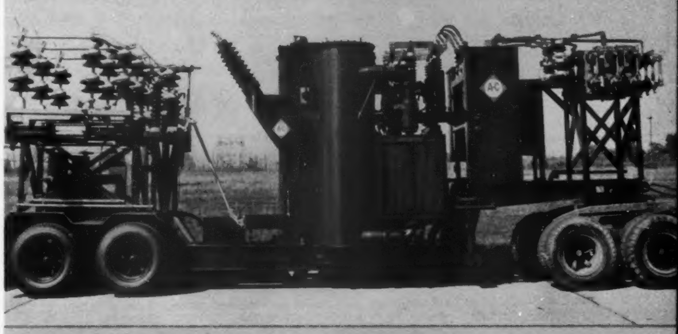
It should be remembered that although these units are obtained primarily for emergencies, the transformers can be loaded and overloaded in the same manner as a conventional transformer. Since most mobile units are forced oil air cooled (Class FOA) the ASA loading guides



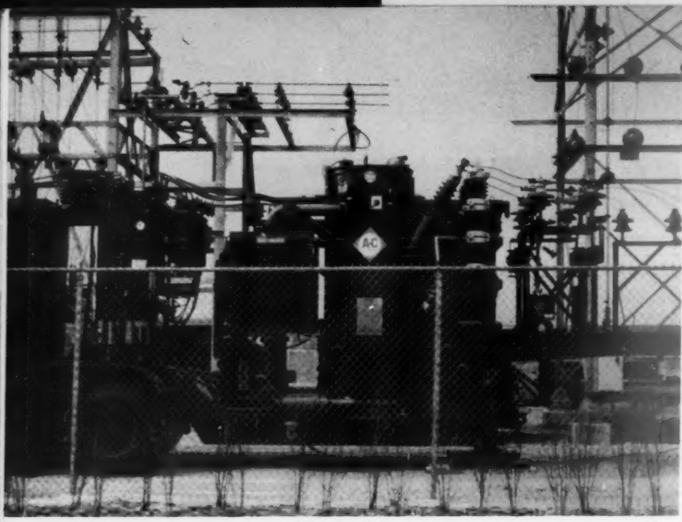
UNUSUAL ALUMINUM WELDMENT used for mobile transformer integral case and frame reduces the weight of 40,000-kva unit to 94,000 pounds. Unit will be mounted on special low-bed trailer for convenient transportation over California highways. **(FIGURE 2)**



MOBILE SUBSTATION, rated 7500 kva, FOA, 3 phase, 43,800 volts delta to 4360Y/2500 - 13,090Y/7560 volts, has primary fuses and secondary breaker ready for connection into the system. **(FIGURE 3)**



VARIETY OF VOLTAGES are usually designed into mobile substations to give them necessary flexibility to readily adapt them to any part of a utility system. **(FIGURE 4)**



MOBILE SUBSTATIONS can be seen in operation in all parts of the country attesting to their importance in system planning.

applying to FOA transformers can be used to determine load capacity. Those units which are designed for average temperature rises in excess of the standard 55 C rise are exceptions. Since transformer capacity is a function of temperature rise, increased ratings can be obtained at these higher temperatures. When mobile capacity is required in excess of that permitted by highway limitations, additional capacity can be obtained by utilizing a unit rated higher than the standard 55 C rise. The following are the increases which can be obtained:

65 C rise — 112 percent of the 55 C rise rating
70 C rise — 118½ percent of the 55 C rise rating
75 C rise — 125 percent of the 55 C rise rating

As an example a unit which has a 25,000 kva rating at 55 C rise can be rated 28,000 kva at 65 C rise, 29,600 kva at 70 C rise, and 31,250 kva at 75 C rise. Mobile equipment is becoming a necessity for most power systems whether they are large or small.

Reduced insulation which has been so effectively applied on high voltage generator and substation power transformers should also be considered for mobile units. The weight reduction made possible by the use of reduced insulation allows larger capacity units for a given weight limitation. Reduction of one or more insulation classes permits increases of five to 25 percent kva ratings. Although the use of reduced insulation is generally associated with transformers having high voltage windings of 115 kv and higher there is nothing to preclude its use on units having windings 92 kv and lower. Reductions in weight and dimensions and savings in initial cost or increased capacity for a specific weight limitation are possible at all voltage ratings.

Continuity of service, which is a major consideration in system planning, can be obtained more economically with mobile transformers than any other method. The mobility, ease of installation, flexibility and low evaluated cost are also other reasons why serious consideration should be given to this kind of equipment.

STATE HIGHWAY LIMITATIONS ON HEIGHT OF MOBILE EQUIPMENT

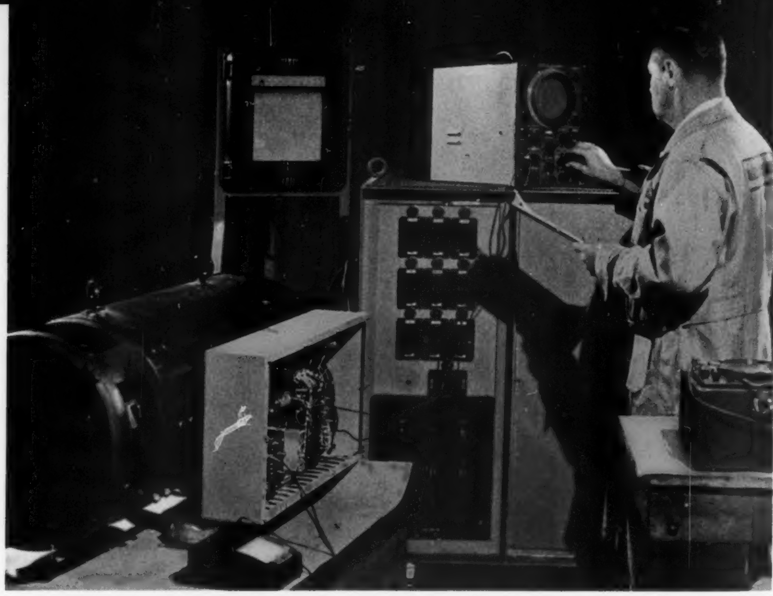
14 ft.	13 ft. 6 in.	13 ft. 0 in.	12 ft. 6 in.
Idaho Utah	Arizona Arkansas California Colorado Florida Georgia Illinois Indiana Iowa Louisiana Kansas Kentucky Michigan Minnesota Missouri Montana Nebraska Nevada New Hampshire New Jersey New Mexico North Dakota Ohio Oklahoma Oregon S. Carolina South Dakota Texas Washington Wisconsin Wyoming	Alaska Hawaii New York	Alabama Connecticut Delaware Maine Maryland Massachusetts Mississippi N. Carolina Pennsylvania Rhode Island Tennessee Vermont Virginia West Virginia

In all cases the maximum width is 8 ft.

STATE HIGHWAY LIMITATIONS ON MOBILE EQUIPMENT

Pounds	State	Pounds	State
120,000	Michigan	71,146	Nebraska
88,000	Rhode Island	68,350	South Carolina
86,400	New Mexico	68,000	Wisconsin
81,600	Hawaii	66,450	Florida
79,900	Utah	66,400	New Hampshire
78,000	Ohio	65,100	North Carolina
76,800	Arizona Alaska California Idaho Montana Nevada	65,000	Maryland New York Arkansas
76,000	Oregon	64,650	Alabama Missouri
75,200	Colorado	63,890	Kansas
73,950	Wyoming	63,280	Georgia
73,280	North Dakota South Dakota Oklahoma West Virginia	62,000	Pennsylvania
73,000	Massachusetts	61,580	Tennessee
72,634	Iowa	61,200	Connecticut
72,500	Minnesota	60,000	Vermont Maine New Jersey Delaware
72,000	Illinois Indiana Louisiana Texas Washington	56,800	Kentucky Virginia
		57,650	Mississippi

In some states a special limited permit may be obtained which permits load limits in excess of those listed.



VITAL LOADS can be protected against momentary power interruptions with modern machines and sensitive controls. The 5-kva uninterrupted power set under test is used for protection of communication systems against power outages.

NEW APPROACHES TO UNINTERRUPTED POWER

F. H. GROOMS and P. D. WAGNER
Norwood Works
Allis-Chalmers Mfg. Co.

Uninterrupted power is assured for vital loads during system power failure with novel generator sets.

STANDBY POWER UNITS of many sizes and types are finding use throughout industry. With standby power units a short transfer interval is required to switch to the emergency power when system power fails. Even these short interruptions cannot be tolerated in certain critical power applications.

A few typical applications requiring uninterrupted power supplies are:

1. Hospital operating rooms for operation of iron lungs, mechanical hearts, mechanical kidneys and lights.
2. Certain military installations.
3. Civil and military communication systems.
4. Complex computers.
5. Nuclear reactor monitoring control and reactor coolant pumps.
6. Ship and aircraft navigational aids.
7. Fire alarm systems.

In one approach to uninterrupted power, a generator set consisting of a generator, motor flywheel, electromagnetic clutch and diesel engine is used. In normal operation, the generator is connected to the load and is driven by the motor which operates on the power system. If the power fails, the clutch is automatically engaged starting the engine which drives the generator. The flywheel carries the set during the transfer period.

While this arrangement has been used for many years, most modern applications of uninterrupted power equipment call for a precisely regulated power output. To provide this power and to gain greater reliability, the uninterrupted power units shown in Figure 1 were developed.

In this design, the generator is of the four-pole rotating field type with distributed field windings. A connected damper system is incorporated to insure good single-phase performance. Commonly used slip rings and their associated brushes have been eliminated by using a rotating rectifier assembly consisting of six silicon diodes mounted on the unit's ventilating fan which also acts as the heat sink. These diodes are arranged in a three-phase, full wave rectifier circuit and convert the ac output from the exciter to the dc required by the generator fields. The exciter yoke and field pole assembly construction is similar to that of a conventional dc exciter, but permanent magnets are placed in the interpolar regions to assure exciter voltage build-up.

Output regulated by static equipment

The voltage regulator for this generator is a controlled voltage compensator using only static and semi-conductor components. The generator output voltage and current are fed through a transformer whose output is rectified to supply the field of the exciter. The generator output voltage is sensed and compared with a Zener reference diode and any correction necessary is accomplished by controlling the saturation of the transformer.

Since the available power in most installations is 60 cycle, single-phase, a single-phase drive motor directly coupled to the generator is used. In some installations,

induction motor drives have been used on the motor-generator sets causing a synchronization problem. While this is not a serious problem in some applications, with the more critical applications, such as television signal transmission, the slip of the induction motor can result in lower quality signals. To completely eliminate this effect, a synchronous motor is used to drive the motor-generator set. To further simplify the system, an unexcited synchronous motor, *Synduction* motor, is used.

The *Synduction* motor is designed to operate over a wide voltage band and maintains good power factor and efficiency on either end of this band. The motor will pull the system into synchronism from above synchronous speed on the lowest voltage power source available and pull-out does not occur until the voltage falls below the rated voltage band. The large flywheel will not permit the motor to pull in from a speed below synchronous speed. A special coupling is utilized to permit pull-in from higher speeds. The coupling is designed to permit the rotor to pull into synchronism before it starts driving the flywheel.

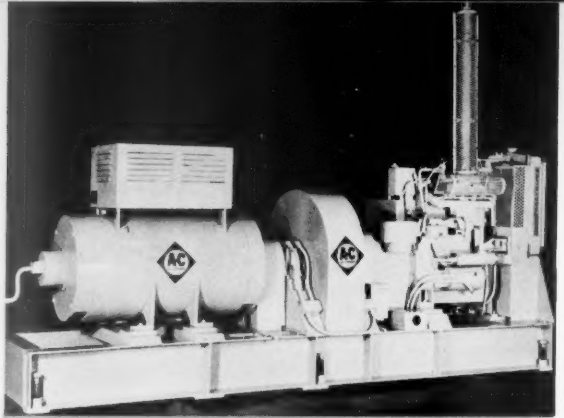
The motor-generator set is mounted inside a fabricated steel yoke and the exciter, generator and motor rotors are mounted on a common shaft. The regulator is contained in a control cubicle directly on top of the set. The flywheel is mounted between two outboard bearings and coupled to an electro-magnetic clutch which activates the diesel engine. This diesel engine is a naturally aspirated type. The fuel, sufficient for 90 hours of emergency operation, is stored close to the diesel engine.

The controls for sensing power failure and for transfer are located in an adjacent cabinet. Several vital parts, such as bearings, are monitored to assure that the set is operating properly. If any malfunction occurs, an alarm signal is transmitted to the nearest manned operating point.

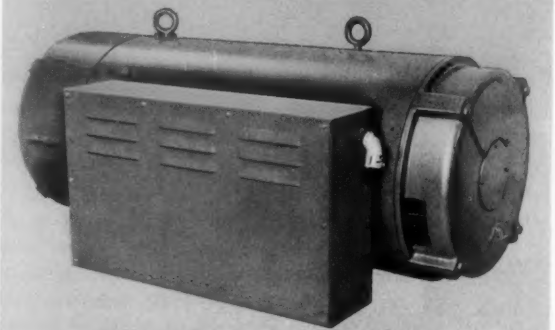
The low values of voltage and frequency droop permitted when transferring from normal to emergency mode of operation requires the use of a large flywheel to store the necessary energy. The flywheel shaft is coupled to the shaft extension of the motor-generator set so both are brought up to speed together. The single-phase motor, required to operate the set under normal conditions, cannot accelerate this system up to synchronous speed. To eliminate using an oversized motor, a manual starting procedure is followed.

Set can be hand cranked

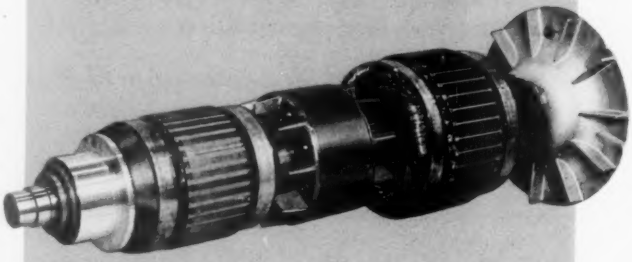
The motor-generator set and flywheel are hand-cranked up to approximately 100 rpm. At this speed the clutch connecting the diesel engine to the flywheel is closed and the engine, cranked by the flywheel, fires and brings the set up to rated speed. When operating speed is reached, the unit is transferred to the power system supply line, the engine is de-activated and loads may be applied on the generator. Once the motor-generator set is running, it is not stopped except for maintenance purposes. The starting procedure also permits construction of the single-phase motor without a starting winding.



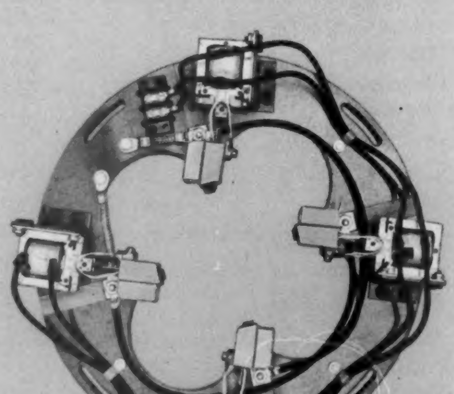
ENGINE SET CLUTCH engages if power source is interrupted and flywheel starts the engine to maintain generator speed. Power to load is uninterrupted. **(FIGURE 1.)**



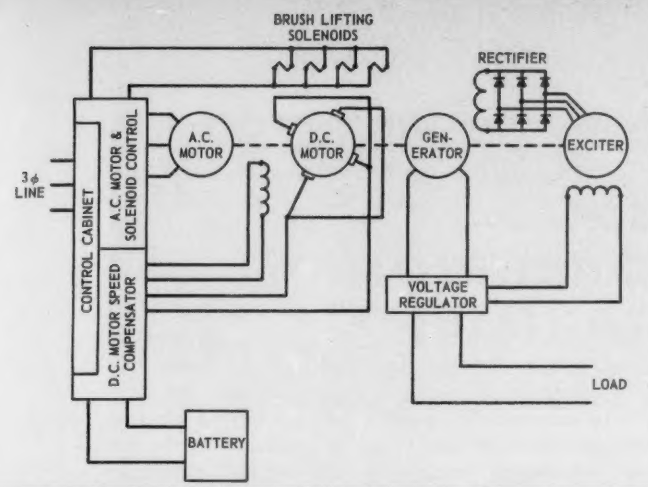
BATTERY POWER maintains this generator set speed if source power is interrupted. Generator output is regulated by static equipment in terminal box. **(FIGURE 2)**



BRUSHLESS-GENERATOR exciter and field are mounted on shaft with *Synduction* motor rotor and dc motor armature. *Synduction* motor is normal prime mover. **(FIGURE 3)**



SOLENOIDS hold brushes off dc motor armature while ac motor drives set. If ac power fails, brushes are released and dc motor drives set on battery power. **(FIGURE 4)**



UNINTERRUPTED POWER SUPPLIES operate with simple proven equipment. Under normal conditions, an ac motor and brushless generator regulated with static equipment supply load. **(FIGURE 5)**

Any failure of commercial power will be detected by the auxiliary automatic control equipment and after a time delay of ¼ second, to prevent false transfers, will act to isolate powerlines from the motor and activate the magnetic clutch. The engine, cranked by the flywheel, is accelerated up to system speed and assumes the function of system prime mover. Power during the transfer period is derived from energy stored in the system flywheel.

When system power is restored to within acceptable limits the *Synduction* motor can again function as a prime mover. However, the retransfer to electric drive is delayed 15 minutes by the automatic control to prevent premature transfer. This delay assures that the power is available again on a continuous basis and the cause for the power outage has been corrected or cleared. The transfer back to normal operation is accomplished by de-energizing the magnetic clutch and cutting off the air and fuel supply to the diesel engine. The system is now ready to react to the next power failure which may occur.

TABLE I
PERFORMANCE OF UNINTERRUPTED POWER SUPPLIES

	5 KW	10 KW
Kva	6.25	12.5
Kw	5 @ 0.8 pf	10 @ 0.8 pf
Current	27 Amperes	54.5
Power Factor	0.7 to 1.0	0.5 to 1.0
Voltage	230	230/115
transient dip	10% with 20% load application; 20% with full load application	<10% with 20% load application; <20% with full load application
recovery time	to ± 5% within 0.15 sec., to ± 1% within 1 sec. — 20% load application; to ± 10% within 0.5 sec., to ± 1% within 1 sec. — full load application	to ± 1% within 1 sec — full-load application
regulation	± 1% (± 2% during transfer)	± 1% (± 2% during transfer)
Overall efficiency	>63%	>65%

Battery power can be used

Another approach to uninterrupted power uses a motor, generator and a dc motor with batteries. Under normal conditions the motor, operating on the power system, drives the generator which supplies the load. If power to the ac motor fails, the dc motor is connected to the batteries and drives the generator without power interruption to the load.

The motor-generator set for this uninterrupted power also incorporates a brushless generator and *Synduction* motor. A 5-kw set is shown in Figure 2.

To make the unit as compact as possible, all rotating equipment is built into a single yoke with a common shaft for all rotors. The dc motor armature, *Synduction* motor rotor, generator rotor, and exciter armature on the shaft are shown in Figure 3. The voltage regulator is attached to the side of this set making it a self-contained unit except for the transfer, starting and speed control equipment which is located in a separate control cabinet. The generator, exciter and regulator are similar to those used in the engine-generator set, except output is single-phase, two-wire.

The ac motor used as main prime mover for this set is again an unexcited synchronous motor. These sets are primarily to be used in stations near largely populated areas where polyphase power is commonly available and have to date been designed only with three-phase *Synduction* unexcited synchronous motors.

Under the normal mode of operation, the ac motor acts as the prime mover with the fields of the dc motor energized at all times. The brushes are held away from the commutator, as shown in Figure 4, by solenoids energized from the ac line. When the ac line power fails, deenergizing the solenoids, the brushes drop, allowing the dc motor to supply power at once. The transfer from normal mode to emergency mode of operation is fast, and no additional flywheel effect is needed to maintain the frequency within very close limits. A voltage regulator maintains the output voltage of the generator during this transfer period. Incorporated in the voltage regulator on this system is the "fail-safe" feature which limits the voltage to 120 percent of the nominal voltage if the regulator were to fail. A diagram for the set is given in Figure 5.

The cooling air for this set is drawn through the unit by a fan on the exciter end. This fan also serves as a heat sink for the rotating rectifier assembly. Special baffles are provided within the unit to guide the cooling air more effectively.

Characteristics of the 5 and 10 kw single phase, 60 cycle sets are given in Table I.

Uninterrupted power systems can be used to increase the reliability of the power flow to critical loads. These systems are gaining in acceptance for industrial, commercial, and military applications. The cost of such a system may be returned by time and material saved because reliable power is available at all times. ◆

Planning for... PROFESSIONAL ATTAINMENT

JOHN GAMMELL
Director of Professional Development
Allis-Chalmers Mfg. Co.

Experience is losing out in competition with new learning.

FACED WITH A WORLD in which engineering knowledge has a probable half life of less than 15 years, the young engineer in industry needs to take cognizance of his position and make long range plans for professional growth. The experienced engineer also needs to evaluate his position to determine if he is making his best contribution.

There are two sound choices for an engineer:

1. If his experience is sufficiently valuable, he can move away from purely technical matters toward management and related functions, and give up engineering except as a background for understanding and decision.

2. He can add his experience to a constantly maintained technical knowledge and continue in engineering.

During the engineer's orientation or early career, his plans will be changed as new knowledge of career opportunities open up and his own capabilities are discovered. During this period his prime purpose is to find out what is available in the way of careers and what interests and capabilities he has that will provide him with an opportunity to make a worthwhile contribution.

Personal appraisal is first step

Before making an intelligent choice between the two paths to follow, the engineer needs to chart his assets and liabilities in much the same manner as making a personal financial appraisal.[1] The chart should include such headings as:

1. My Job
2. My Profession
3. My Personal Development Progress

Having made this self analysis, a career objective can be established and the first steps required to meet this objective considered.

Continued education along either of the two approaches to professional attainment is one of the first steps in a plan for professional growth. This education can be a united effort of the employer, of academic institutions and of professional societies, but starting and finishing this program are the responsibility of the employe. The great majority of engineers are employed in urban communities where educational opportunities are available and even in those cases where they are not available, programs can be laid out by the individual for his purposes.

One of the most effective ways of keeping up is to attend the technical society meetings. Because technical societies are constantly probing for up to date program material, they serve well in introducing their members to advanced subject material. In some cases, technical societies through seminars and courses go beyond the introduction stage. These societies are also excellent means for developing speaking, writing, and leadership through participation in meetings and committees.

Registration an achievement

Registration under the state laws for engineers is an important goal. There are solid legal reasons for registration, particularly if the engineer's work involving the health, safety or welfare of people is questioned. There is also the matter of personal identification with the profession which is supplying him with a valued career. Professional identification must include the practice of good ethics as applied to:

1. Professional life
2. Relations with the public
3. Relations with clients and employers
4. Relations with other engineers

If these principles are not followed, the engineer's career will be subject to harassments requiring his time and attention, thereby greatly lowering his effectiveness in getting things done.

A further aid in career building is the development

of responsible citizenship. Every employer is proud to have people associated with him who are well respected in their communities. Respect is gained through judicious participation in worthwhile activities. The selection of what to do, how much time to give to which welfare, educational, political, church and professional activities of the community is admittedly difficult to decide, but to withdraw is weakness.

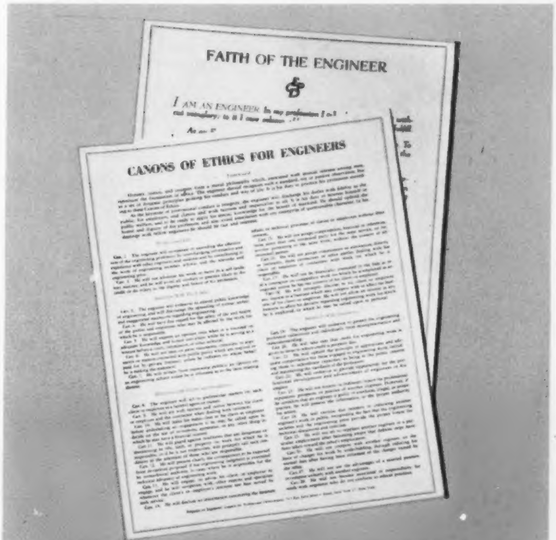
There is some indication that at least 50 percent of our young engineers will eventually have jobs which are primarily administrative if not actually managerial. The problem for the engineer wishing to follow this path is one of understanding a host of matters concerned with marketing, finance, law, government regulations, and economics. These subjects should be a part of his continued education and will be among his daily concerns. A planned reading program will aid in these areas.

The need for engineering information is shown by the growth in the number of engineering societies. One hundred years ago there were four recognized engineering or scientific societies in the United States, 20 years ago there were 97, and last year there were 167.[2] As we walk through the halls of any large corporation we see job titles on office doors that didn't exist a few years ago. Computer technology, modern mathematics, chemistry and physics, have created a host of new techniques. It is now impossible to keep up with even the narrowest field without special effort.

There is said to be six times the chemistry to learn today as 32 years ago. Other disciplines are experiencing similar explosions of technology. The young engineer of today has a major task in carefully selecting his area of operation and keeping abreast of it. It is evident that many engineers of the past have not kept up, as indicated by the unusual inducements put forth by company college recruiters to attract the academically able young men from the better engineering schools. The magnitude of the effort put forth in recruiting these young men because of their up to date technical knowledge would indicate that American industry currently puts a high premium on technical know-how.

The question might be asked of what use is 20 years of experience in old established techniques, when you want to get to the moon or build fusion power plants involving new techniques. But it can be said technical knowledge alone cannot efficiently get things done. It is apt to be too expensive, impractical and time consuming. The correct approach is of course to combine engineering experience with new learning.

To become truly valuable in either management or engineering areas, the engineer striving for professional attainment, today more than ever, is required to place special effort on continually adding new carefully planned learning to his background and experience. Experience can win out in competition with new learning only when augmented by a planned program of professional development and education.



"CANONS OF ETHICS FOR THE ENGINEER" and **"FAITH OF THE ENGINEER,"** published by the Engineers' Council for Professional Development, serve to inspire the engineer to follow policies worthy of his profession.

GOALS FOR PROFESSIONAL ATTAINMENT must be based on earnest self appraisal and serious consideration of fields in which one wishes to excel.

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2. "Where Does Professional Specialization Belong in the Engineering Curricula in Relation to Industry Needs?", paper, Lloyd E. Elkins, Engineers' Council for Professional Development Annual Meeting, Louisville, Ky., 1961.
3. "The Unwritten Laws of Engineering," W. J. King, *Mechanical Engineering*, May-June-July, 1944.
4. "The Engineer in Industry in the 1960's," book, published by the National Society of Professional Engineers, Washington, D. C.
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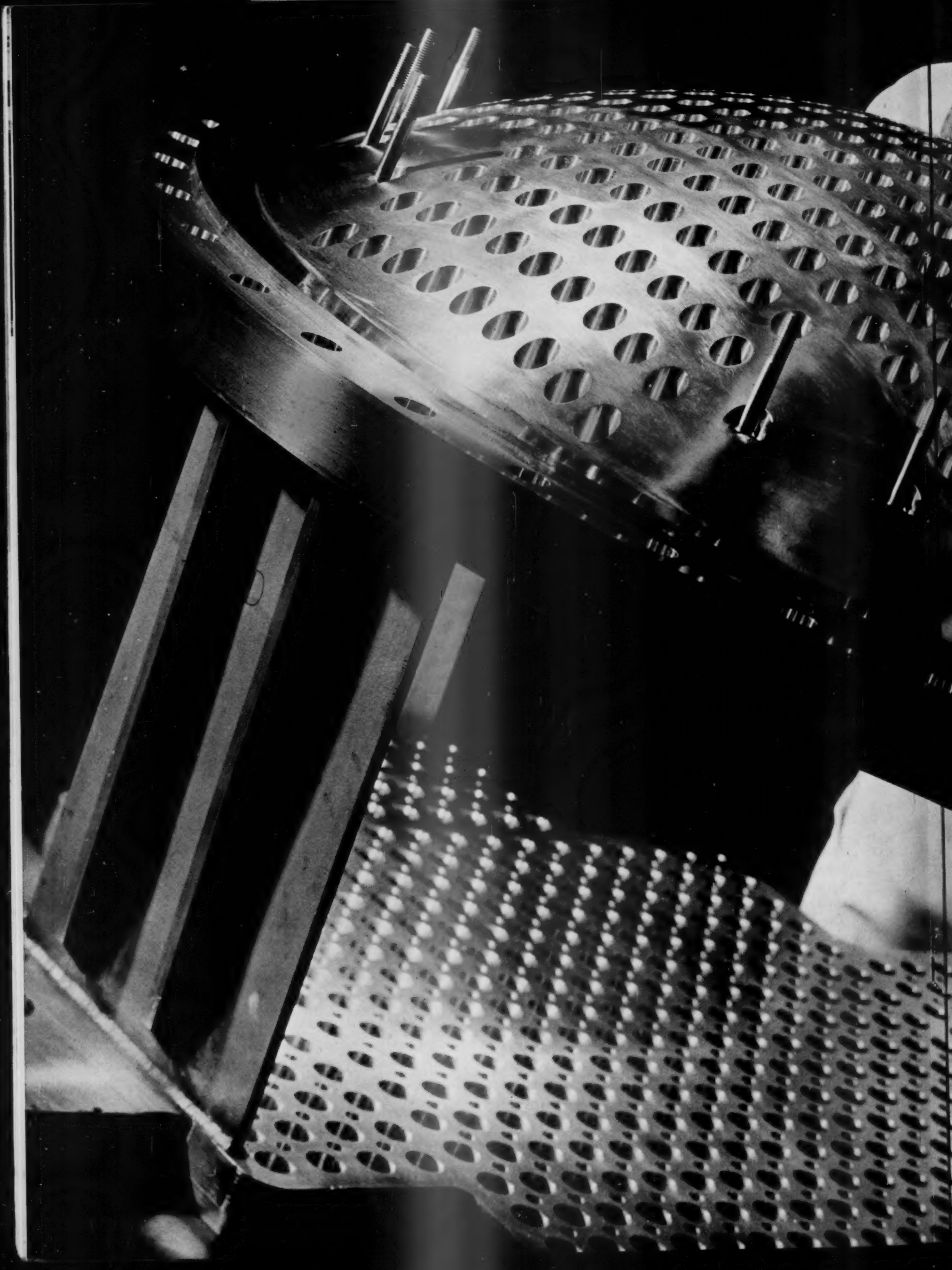
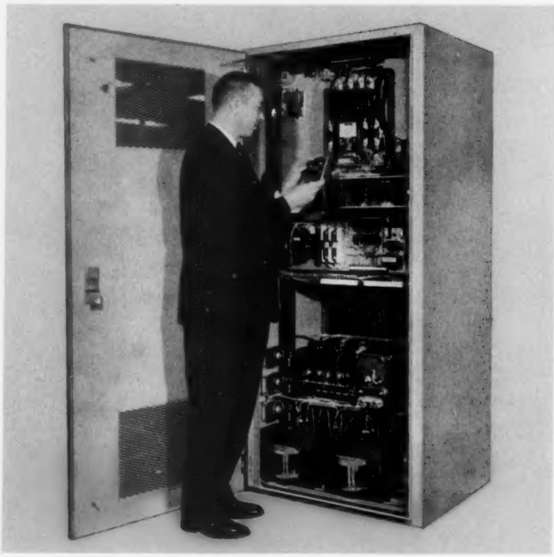
FIRST ALL-NUCLEAR GENERATING STATION, Northern States Power Company's Pathfinder Atomic Power Plant, incorporates the concept of a two-region boiling-superheating reactor originated by Allis-Chalmers. Utilizing nuclear fuel not only as a primary source of energy for producing saturated steam but also as fuel in an integral superheater, steam temperature to turbine is increased to provide greater plant efficiency. Station will be in operation in 1962. The precision drilled stainless steel grid plate, shown inverted, will support and position superheater fuel elements in the reactor core.
Allis-Chalmers Staff Photo by Michael Durante



MODULAR APPROACH TO ADJUSTABLE SPEED DRIVES



NEW ADJUSTABLE SPEED DRIVES for general industrial application make full use of modern static devices in compact design for ratings up to 200 hp. Drive shown has 30-hp, 460 volt rating.

J. T. CARROLL
Control Department
Allis-Chalmers Mfg. Co.

Static regulating devices in adjustable speed drives now have modular design for greater flexibility.

A SIGNIFICANT CONTRIBUTION to the modernization of adjustable speed drives has been made by the introduction of solid state devices to control circuitry. The transistors, semi-conductor rectifiers, and controlled rectifiers make possible amplification, power conversion, and power modulation at efficiencies beyond the capabilities of earlier apparatus. The availability of silicon controlled rectifiers in ratings from one ampere through 150 amperes and from 100 to 500 volts with essentially uniform actuating requirements now justifies their use in basic control circuits throughout the entire range of variable speed drive ratings.

The transistor and its associated components are well suited to the construction of study, reliable and compact control circuitry. By treating each function in the control circuit as an entity, a modular design approach can be readily adopted. Modular units provide reference voltage, timed linear application reference, armature current limit, dc amplification, and field range control. A single firing circuit can provide phase control to the various ratings of controlled rectifiers in the modules.

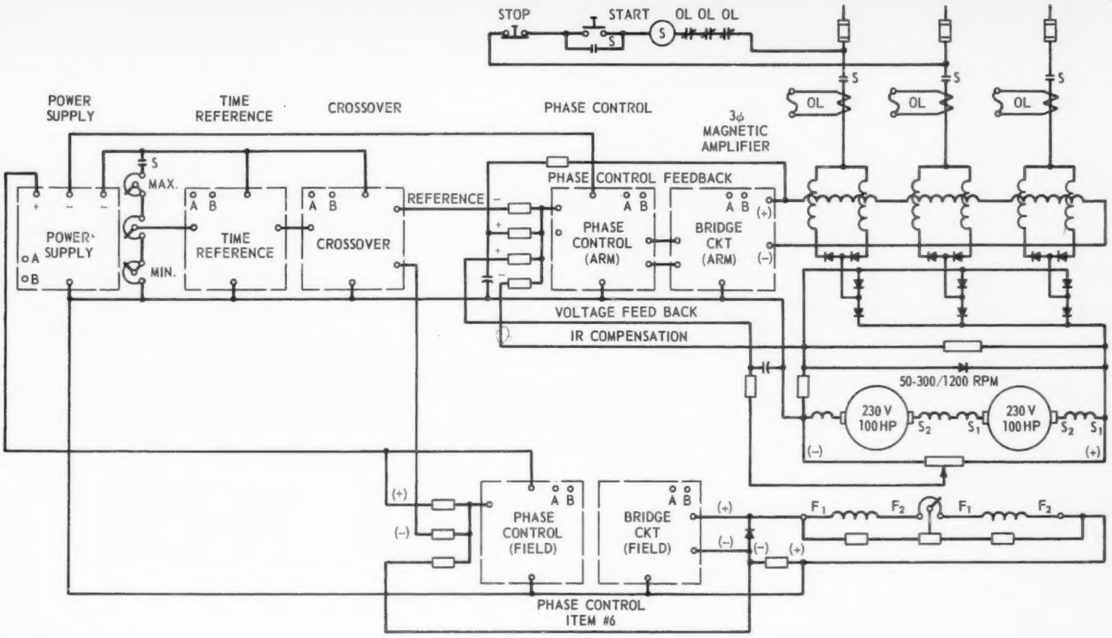
An application of the module concept, shown in Figure 1, furnishes variable speed control of two series connected 230 volt, 100 hp, dc motors driving a 30-ft boring mill. Speed is controlled by armature voltage variation from 50 to 300 rpm base speed and by field weakening from 300 to 1200 rpm. Acceleration control is provided by linear application of reference voltage with time.

Modules are functional

The power supply module, shown in Figure 2, provides isolation and conversion of ac line voltage into three channels of regulated dc voltage. These dc supplies each originate from a common full wave dc source, and after adequate filtering, supply three Zener diode shunt regulators which provide stable output voltages despite fluctuating load and supply line conditions. These dc supply voltages provide excitation to the time reference, crossover, and phase control modules. In addition, one source is used as a reference voltage. This reference voltage is connected to a series of rheostats in a voltage divider network circuit. The network provides a speed setting means through a centrally located potentiometer, and maximum and minimum speed adjustment by those rheostats located above and below the speed setting potentiometer. The operator selects a reference voltage proportional to the speed he desires and this voltage is connected to the input of the time reference module.

The time reference module operates upon a sudden change of input voltage to generate an output which increases or decreases linearly with time to a value coincident with the input value of voltage. The circuit prohibits severe voltage change thereby limiting acceleration and deceleration torques and currents to values consistent with equipment capabilities. Separate adjustment of the acceleration and deceleration time is possible. Constant current regulators located within this module charge a capacitor at constant current to provide linear buildup of voltage. Two stages of current amplification match capacitor voltage to module load. The output of the timed reference module is then connected to the crossover circuit.

The crossover module is provided in the drive control equipment to permit speed variation by altering armature voltage and field current through a single speed setting potentiometer. The module operates upon the speed refer-



CONTROL FUNCTIONS are divided into compact control modules. Each module is preassembled ready for application to the circuit. **(FIGURE 1)**

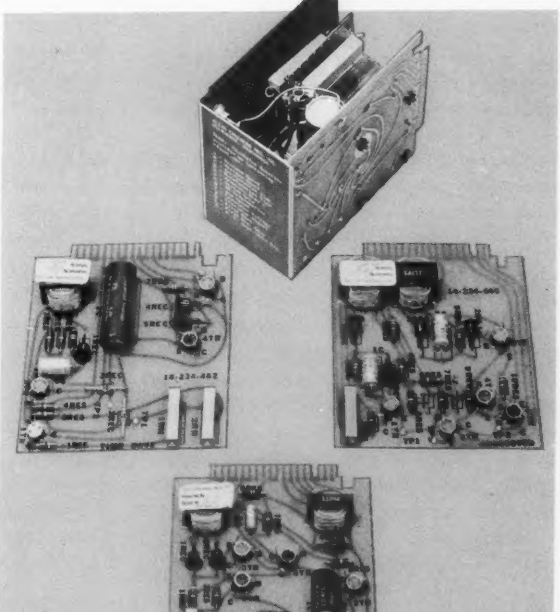
ence signal as taken from the time refrence module to divide and direct it to either the armature or field regulator, depending upon the desired speed of operation. One output directs the module input voltage to the armature regulator from the minimum reference voltage level to a value which is representative of the machine base speed. The second output remains at essentially a zero level until base speed is obtained. When base speed is reached, a second signal starts to reduce the field current and thus further increases motor speed. The armature range output reproduces the input voltage until the crossover level (base speed) is reached. It then remains constant despite the further application of input voltage.

The field output which remains nearly zero, until the crossover point was reached, will begin to rise with the application of voltage as the crossover point is exceeded. The field output will increase in a nonlinear fashion to produce equal speed changes for equivalent increments of speed setting potentiometer position. A shaping network produces a field range output which will linearize the typical field current versus speed characteristic for a dc motor. A crossover level adjustment is provided to preset the voltage at which field weakening commences. The speed setting potentiometer may, therefore, be prorated between armature and field speed ranges to match the ratio of top speed in the field range to base speed of the motor.

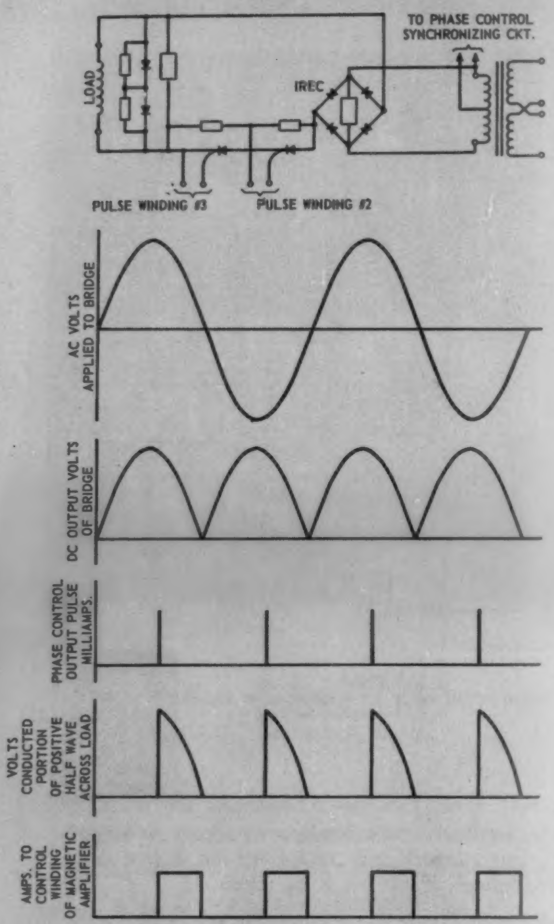
High gain with static devices

The armature output of the crossover module is connected to the phase control amplifier which sets the output voltage of the three phase magnetic amplifier. The phase control module in conjunction with its silicon controlled rectifier performs in the system as an amplifier with very high power gain. This device compares the armature reference, feedback, and compensating signals and operates on their algebraic sum, to furnish the desired value of speed, voltage, or current at the output.

As shown in Figure 3, the controller generates a pulse at varying points along the positive half of the sine wave



POWER SUPPLY MODULE (upper unit) provides regulated supply and reference voltages for other functional modules. **(FIGURE 2)**



PULSE POSITION is controlled by error signal and governs control current in magnetic amplifier supplying load. **(FIGURE 3)**

applied to the anode of a controlled rectifier. The variation of pulse position causes more or less anode supply voltage to appear directly across the load of the amplifier which, in this case, is the control winding of a three-phase magnetic amplifier. If the pulse occurs early in the conductible portion of the half-cycle, a nearly maximum amount of power will be transmitted to the load. If the pulse is retarded until rather late in the half-cycle, minimum power is supplied to the load.

The relationship between pulse position and input signal is approximately proportional provided negative feed back is employed. The output of the three-phase magnetic amplifier, connected to the dc motor armatures, is then proportional to the amount of signal or voltage provided by the output of the control bridge rectifier circuit. The output voltage of this magnetic amplifier is then fed back to the phase controller through the feedback circuit. The summation of the feedback voltage and the armature reference voltage then provides the error signal which establishes the operating level of the phase controller and consequently the output voltage of the three-phase magnetic amplifier.

IR drop compensation provided

Since the speed regulation is based on voltage, the motors will drop in speed with load because of armature loss. To compensate for this effect, a signal proportional to armature current is fed back to the phase control input in such a manner as to aid the established reference voltage thus restoring the machine to the required output speed.

The motor field supply phase control amplifier operates in much the same manner as the armature voltage regulator, except that the controlled variable in the field regulator is current. The field phase controller is simply supplied with reference, feedback, and excitation voltages of an opposite polarity to that supplied the armature phase controller. A positive bias voltage drives the phase controller to near maximum output, providing full field current to the drive motor. The cross-over voltage signal is of negative polarity as it appears at the input of the field phase controller, thus driving the output downward.

In effect a lower net reference level is established causing the machine field current to diminish. A signal proportional to the field current is derived across a current sensing resistor, and is fed back with negative polarity to oppose the positive bias or reference voltage. The shaping characteristic of the crossover field output, in conjunction with the proper level setting in the crossover and series resistance adjustment at the input to the field phase controller, provides a linearizing effect between reference voltage settings at the speed setting potentiometer and output speed of the machine.

Current limit control available

Although it is not shown in Figure 1, a current limit acceleration control may be provided as an option to the time reference module. The current limit module derives an input signal from a current sensing resistor in the dc motor armature circuit. The module then responds to a preset input signal proportional to the armature currents. Its output is essentially zero until the limiting level of armature current is obtained. At which time the output increases to a value sufficient to inhibit further rise of armature current. The threshold of current limiting may be adjusted from 100 to 200 percent of full load motor current. The purpose of such a circuit is to provide acceleration control within machine and mechanical drive limitations, under all types of loading including variable inertia.

The availability of high power gain in this regulator in conjunction with extremely fast response makes possible improved system accuracy while simplifying stabilizing networks. The system provides speed regulation well within the five percent of base speed normally specified for this type of drive. Since all reference supply voltages are regulated the system displays relative immunity to line voltage variation.

Modules on individual cards in file

These basic circuits are formed by a photo-etching process on a copper-clad laminated card. The card material is an epoxy glass laminate $\frac{1}{16}$-inch thick. Electrical components are inserted, soldered, and fastened to this laminated support as shown in Figure 2. Components of more than minimum mass are rigidly fastened to the board. The

individual circuits are constructed on a single card which is formed to provide a male connector on one edge. The edge of the card which forms this male plug mates with an etched circuit connector. The cards, connectors, and card supports are housed in a panel card file assembly. The individual modules can be selected to meet the application requirements.

The module file assembly provides support and protection to the individual modules and their respective plug-in connectors. The assembly is panel mounted in with each circuit in a vertical position, minimizing the settlement of dust on the circuit card and individual components. Each circuit possesses a unique polarizing scheme to insure card insertion in the correct position properly oriented with respect to top and bottom. All cards are latched firmly into their guides, connector pressure is not relied upon. Each card, prior to insertion into the card file, is sprayed with two coats of clear acrylic plastic. This substance is applied to each side of the card providing insulation of 400 volts per mill while preserving component identification and symbols. This procedure excludes humidity and detrimental agents normally encountered in an industrial application. In particularly hostile environments, the card may be treated with an epoxy encapsulating compound which virtually produces a hermetic seal between the atmosphere and all components mounted on the circuit board.

Devices proved for industrial environments

Specified performance has been obtained for each circuit under conditions of elevated ambient temperatures of up to 60 C with fluctuating supply voltages of plus or minus 10 per cent of nominal. Constructional features have been evaluated under conditions of mechanical vibration considerably in excess of that which may be expected in industrial environment. Frequencies between 10 and 60 cycles per second were explored to establish any resonance. All modules successfully withstood 10 hours of 60 cycle vibration at 2G's RMS without failure or deterioration in performance.

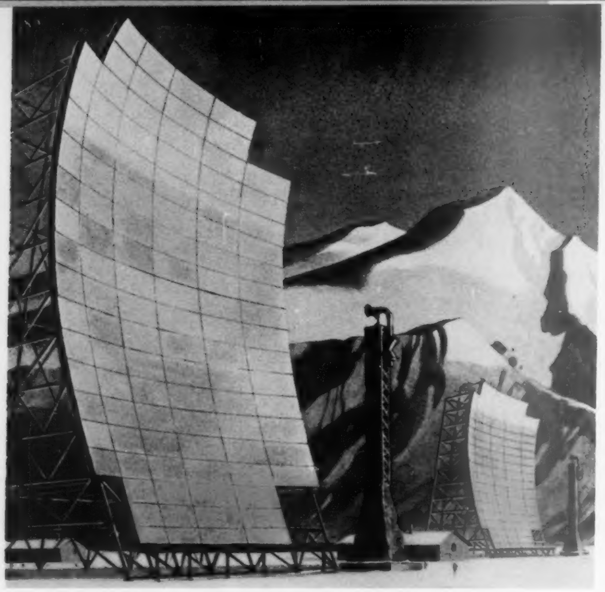
The conservative application of solid state devices within their specified limits provides the ultimate in reliability. Conveniently located test points readily accessible on the front edge of each circuit card facilitates checkout and tune-up procedures. A multi-tester or voltmeter with its positive probe connected to the system common, may be used to check reference voltage level and the magnitude of input and output voltages at each module, as shown in Figure 6.

The continued application of semiconductor technique and modular packaging concepts will provide significant benefits to industrial users. Solid state circuits will provide overcurrent and overvoltage protection, and it will soon be economically and technically feasible to support a motor armature through three-phase controlled rectifier bridge circuit. These new concepts of circuit design and construction promise the advantage of more compact, reliable, and maintainable control equipment with improved performance. ◆

MOTOR STARTER connects drive to line and provides necessary overload protection and means for remote control. **(FIGURE 4)**

MODULE CARDS are carefully checked in special machine to assure interchangeability between cards for like applications. **(FIGURE 5)**

TEST POSITION is provided with card file arrangement to simplify inspection and testing of individual cards in the field. **(FIGURE 6)**



REMOTELY LOCATED RADAR STATIONS require utmost in reliability. New protective devices were developed to meet the needs of this vital equipment.

HIGH SPEED PROTECTION FOR RADAR POWER SUPPLIES

JOHN BAUDE and S. E. McDOWELL
Switchgear Department
Allis-Chalmers Mfg. Co.

Specially designed high speed relaying and fast breaker provide protection for vital radar power supplies used in United States defense system.

UNITED STATES defense effort is centered around several projects such as the DEW line (Distant Early Warning), BMEWS (Ballistic Missile Early Warning System), and now NIKE-ZEUS (Interceptor Missile or Anti-Missile Missile).

All of these systems employ extremely high power radar equipment for surveillance, far-out acquisition, discrimination or tracking of hostile aircraft or missiles. The DEW line and project BMEWS are, as the names suggest systems to give early warning of enemy attacks on the United States so that citizens can be alerted and retaliatory action in the form of SAC (Strategic Air Command) bombers and U. S. missiles can be launched. The Nike-Zeus system utilizes three separate radar equipments: The first is the ZAR (Zeus Acquisition Radar) whose job is the far-out acquisition or detection of high speed missiles approaching the United States. As soon as a missile is acquired, the second radar, ZDR (Zeus Discrimination Radar) takes over to determine if the missile is friendly or hostile. Hostile missiles are then tracked by the third radar set which automatically "locks-in" on the missile and signals the firing of the Nike-Zeus rocket to intercept and destroy the enemy missile.

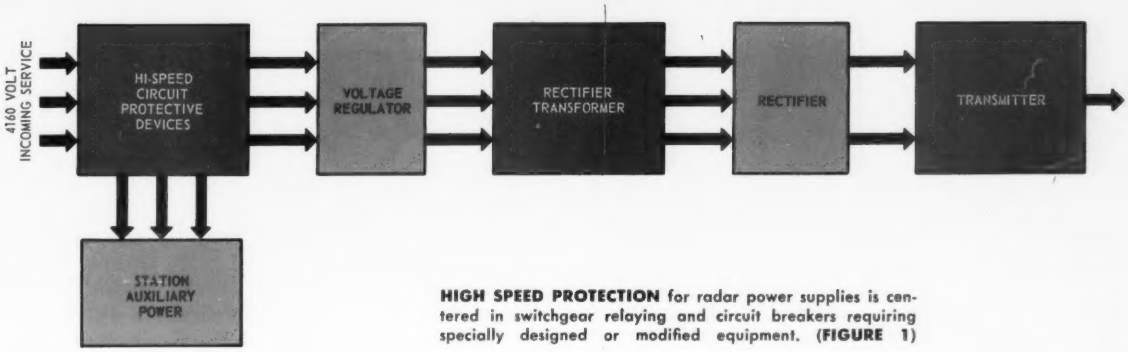
The high power radar equipment of these defense systems must have an extremely high degree of reliability if they are to be effective. To achieve this reliability, many problems had to be solved by the manufacturers of the radar transmitters and the associated equipment. To meet the rigid requirements, new components were developed for use with conventional switchgear to provide high speed protection for the radar power supplies and for the power Klystron tubes. A typical power supply is shown in block diagram form in Figure 1.

Basically, the Klystron tube consists of an electron gun, which is the source of an electron beam, an r-f section in which the beam is modulated to producer r-f power, and a collector to collect electrons and pass them to external circuits leading to the beam power supply. In equipment utilizing power klystrons, extremely fast devices are required to protect them against damage from the malfunction of associated equipment or of the Klystron itself.

Two cycle interruption required

To provide this protection against malfunction, a two cycle interrupting device, a suitable tripping arrangement and a sensing device are required.

A vacuum switch was considered but tests on a simulated transmitter circuit indicated that while the vacuum switch met the two cycle interrupting time under normal load conditions, it would require a back-up breaker to provide short circuit protection. As a result of these



HIGH SPEED PROTECTION for radar power supplies is centered in switchgear relaying and circuit breakers requiring specially designed or modified equipment. **(FIGURE 1)**

tests, a five-cycle air magnetic circuit breaker was modified to provide two cycle interruption time under normal or fault conditions.

Two modifications of a standard commercially available five cycle air magnetic breaker where necessary to obtain two cycle interruption over the range of currents to be encountered in this application. First, at the low currents encountered, such as 150 amperes, a larger volume of air than normal is required in the arcing zone and this air is needed earlier in the interrupting period to reduce interruption time. To supply the quantity of air needed the auxiliary air pumps or puffers shown in Figure 2 were adopted. The puffer linkage to the operating mechanism was altered to introduce the air into the arcing zone earlier.

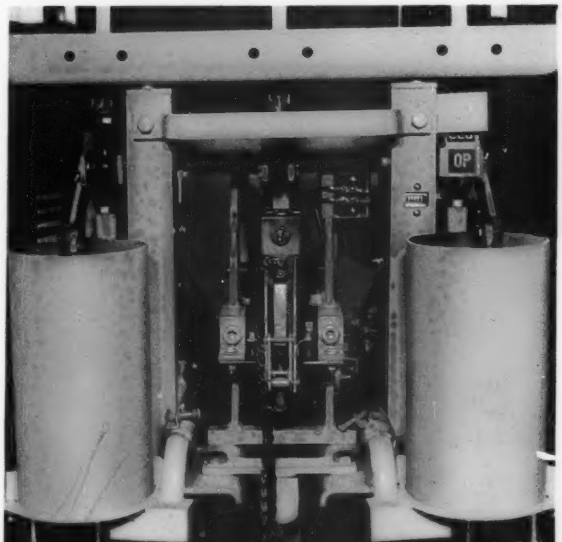
Second, the standard shunt trip device was replaced with the magnetic trip latch. The latch works on the principle of the deflection of the permanent magnet flux from its path through the armature to a path through the coil gap when the coil is de-energized. This reduces the flux hold on the armature to the point where the biased latch, shown in Figure 3, forces the armature to drop away tripping the breaker. Figure 2 shows also a close-up of the hi-speed magnetic latch.

After these developments were completed, a breaker was tested to demonstrate its interrupting capabilities when applied on simulated equipment circuits. In these tests, the equipment was operated under normal conditions and various load outputs and under abnormal or fault conditions by short circuiting the dc output at various load settings. The results of these tests verified earlier factory tests.

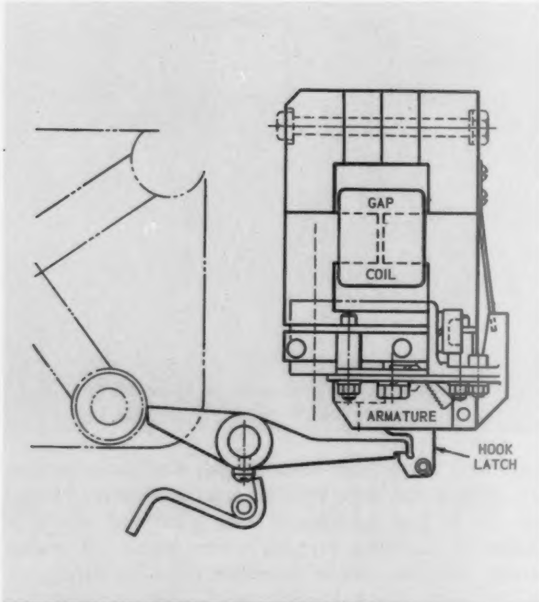
After the two cycle air magnetic circuit breaker had been developed, the problem of obtaining proper devices to sense incipient malfunctions and initiate tripping remained. Figure 4 shows the schematic diagram of the power supply feeder breakers. Normal protective relaying is furnished by inverse time overcurrent relays with instantaneous attachments, device 50/51, and by current balance relays, device 46. Both of these relays are commercially available devices and posed no particular problem. However, no device was available to satisfy the conditions set forth by the transmitter manufacturer. These were: To provide instantaneous overload protection responsive to the peak value of a pulse of beam current and also to the duration of this pulse and which is capable of initiating tripping action within 20 microseconds from the time of exceeding the relay setting.

Protection based on pulse peak and duration

To meet this requirement, the pulse contour relay, shown in Figure 5, was designed to monitor the pulse shape of Klystron beam current. The relay consists of three separate components in semi-flush drawout type construction: Pulse height sensing unit, pulse width sensing unit, and test unit operational simulator and power supply. These components are shown in Figure 7.



LARGER PUFFERS were designed to assure reliable 2-cycle breaker operation even under light loads. High speed magnetic trip latch replaced standard shunt trip device. **(FIGURE 2)**

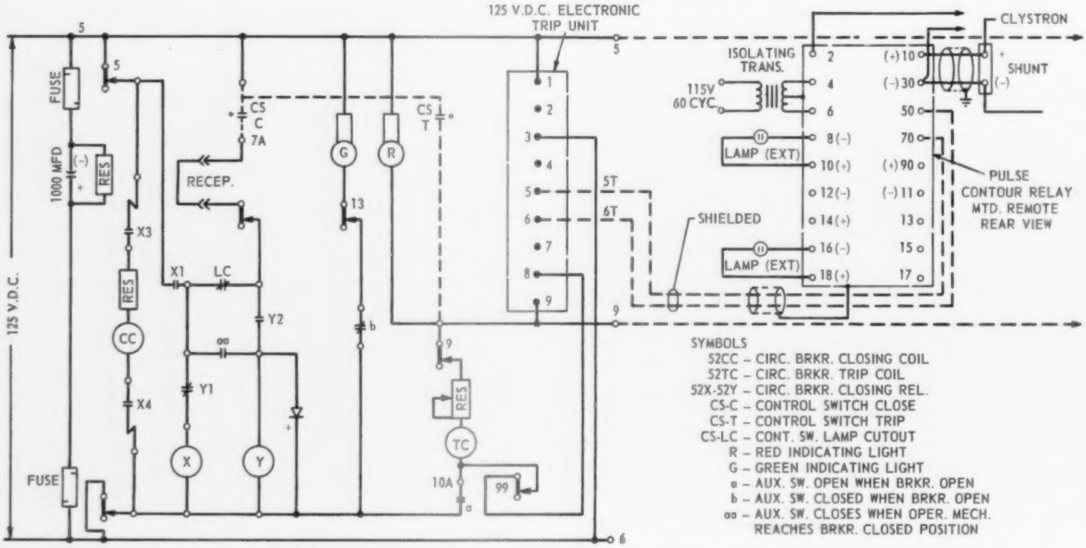


MAGNETIC TRIP DEVICE for 2-cycle circuit breaker is used for faster response to trip signal from the high speed protective relays for radar power supplies. **(FIGURE 3)**

BREAKER CONTROL CIRCUIT includes new electronic trip unit and pulse contour relay for high speed sensitive tripping for overload protection responsive to the beam pulse peak current and to beam pulse duration. **(FIGURE 4)**

The unique performance obtained with the pulse contour relay is based upon the individual functions of the pulse height sensing unit and the pulse duration unit. Any point of an irregularly shaped electrical pulse can be vectorially located by measuring instantaneous amplitude and time. The pulse height or pulse amplitude sensing unit monitors the instantaneous value of the electrical pulse to be measured and its transistorized circuitry functions within a few micro seconds to detect excess amplitude and lock in at the moment the pulse amplitude is exceeded by a predetermined amount set on the control dial. For instance, if the control dial on the front of the unit is set for a maximum pulse current amplitude of 50 amperes, current pulses exceeding this value will trigger the transistorized circuitry into a locked condition which causes the circuit breaker to be tripped by means of the static power trip unit into which the pulse amplitude sensing unit sends its signal. The pulse timing or pulse duration unit monitors the maximum allowable time during which a pulse of maximum allowable amplitude may exist. If this time is exceeded the pulse time duration unit functions in a similar manner to the pulse amplitude unit and emits a signal to the static transistorized power trip unit and triggers it into conduction thereby tripping the power circuit breaker in time to protect the Klystron tube from burnout. Pulse height and pulse duration unit function is separately monitored by individual indicating lights, located on each unit, and parallel connecting terminals are provided for connection to a remote annunciator.

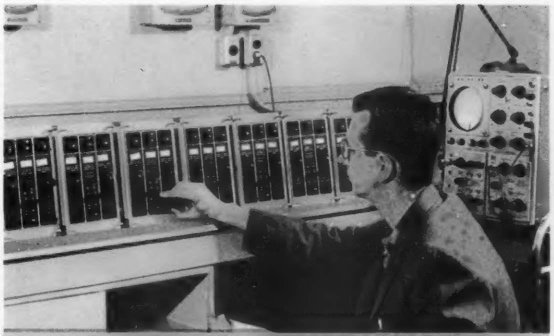
The use of the pulse contour relay concept for detection and control of transient power line conditions is obvious. Precise relaying based upon current or voltage amplitude and duration falls into the class of high speed



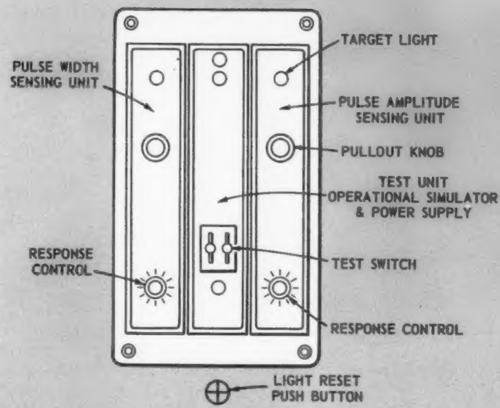
relaying and the performance results of these static transistorized high speed relays can hardly be matched with conventional electromagnetic relays. A third unit is provided also which merely functions as a power supply unit, arranged to provide the necessary operating power for the transistorized relay circuitry and which has been equipped in addition to this with test facilities to permit calibration of the pulse amplitude part of the contour relay when the timing unit is in operation and vice versa.

Figures 5, 6 and 8 illustrate the calibration and testing operations on the contour relay.

The development of the two cycle breaker to give the fast circuit clearing and of the pulse contour relay to give positive as well as fast and reliable monitoring of pulse currents, has also aided the manufacturers of power Klystrons during manufacture and test. It is normal procedure in the manufacture of these tubes to apply high potential dc during the break-in period at which time impurities break away causing a momentary gas burst in which the vacuum drops sharply and possibly tube oscillation is created. Unless the power supply is interrupted less than two cycles, it is necessary to halt the testing and reestablish a vacuum before continuing. Should the tube be allowed to oscillate for a short time it can destroy itself in that it is unable to dissipate the heat generated by oscillation and as a consequence will melt. With the new contour relay, the fault can be removed before any serious trouble develops and the break-in of the tube can continue without delay and without any fear of tube damage. Tube break-in can be accomplished in a matter of two to three hours instead of the previous two to three day period required without high speed protection.

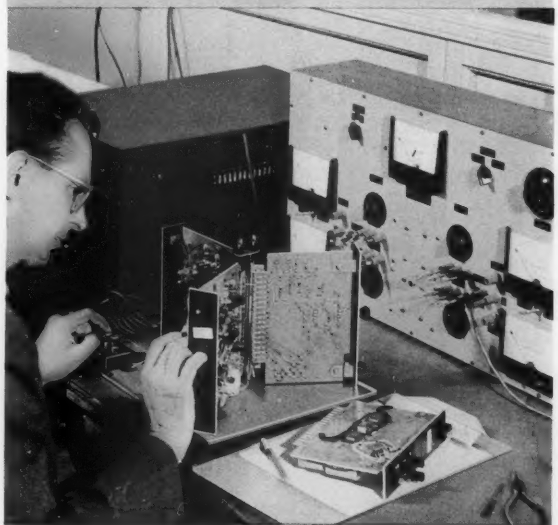


CAREFUL CALIBRATION of each contour relay gives assurance accurate operation when called upon. **(FIGURE 6)**



COUNTER RELAY consists of three sections needed to protect the Klystron tubes in the radar power supplies. **(FIGURE 7)**

TRANSISTORIZED CIRCUITRY is used in radar power supply protective relaying. Complete relay is tested at elevated temperatures to assure consistent operation. **(FIGURE 5)**



RELAY SECTIONS, made up entirely of static transistorized circuit, are readily accessible for test or inspection. **(FIGURE 8)**

EHV TRANSMISSION ECONOMICS

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Load and distance are prime considerations when determining optimum transmission voltage.

ELECTRICAL POWER, TODAY, can be moved from generating station to distribution system at half the cost of moving fuel from mine to generating station.

For this reason, many generating sites are being located close to major fuel reserves and adequate water supply, on the assumption that an economical transmission distance would reach any area of concentrated load, as shown in Figure 1.

The formula used to determine total cost of transmitting electrical power is similar to past economic studies, and is given in Figure 2. The expression is straightforward and readily lends itself to digital computer programming. In the equation the first term inside the large brackets denotes operating costs and the terms inside the small brackets represent capital expenditures.

Before progressing with transmission cost studies, certain approximations must be made to simulate actual operating conditions of a representative power company.

The following assumptions are made:

1. Per unit annual carrying charge on invested money of 16 percent.
2. Load factor of 65 percent.
3. Loss factor of 54.5 percent.
4. Capitalization costs of transmission line power losses, \$150/kw.
5. Energy losses were evaluated at 3.5 mills/kwhr.
6. \$8/kvar as cost of sending end series capacitor reactive compensation.

Cost curves plotted

Figure 3a, b, c illustrate cost curves from which chosen values can be taken and used as input data for a digital computer program based on the equation. Use of a computer in evaluating the equation permits greater accuracy and provides wider scope than manual methods. Despite the natural urge to propose standards for adoption of EHV classification, ratings of equipment already manu-

MAJOR COAL RESERVES in United States are within economical transmission distances from concentrated load centers. **(FIGURE 1)**

Anthracite · Low Volatile Bituminous and Subbituminous · Medium and High Volatile Bituminous · Lignite

$$\text{Total Cost} = \frac{1}{8.76 L_f P_r}\left\{ 8.76 \Delta P L_e C_e + I\left[M C_l + \Delta P C_p + Q_{sc} C_{sc} + N C_b + KVA_s C_{ts} + KVA_r C_{tr} \right]\right\}$$

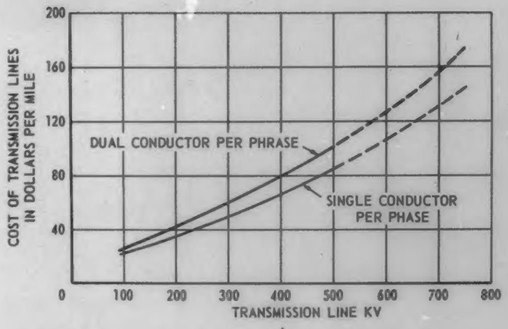
where:

I	Per unit annual carrying charges on investment
L_f	Load factor
P_r	Peak load in kw
M	Miles of line
C_l	Installed cost of transmission line in $/mile
ΔP	Power loss in kw
C_p	Cost of power losses in $/kw of equipment which supplies losses
Q_{sc}	Series capacitor line compensation in kvar
C_{sc}	Cost of compensation in $/kvar
N	Number of circuit breaker positions
C_b	Cost of circuit breakers in $/position
KVA_s	Sending end kva
C_{ts}	Cost of sending end transformers in $/kva
C_{tr}	Cost of receiving end transformers in $/kva
KVA_r	Receiving end kva
L_e	Loss factor
C_e	Cost of energy losses in mills/kw-hr.

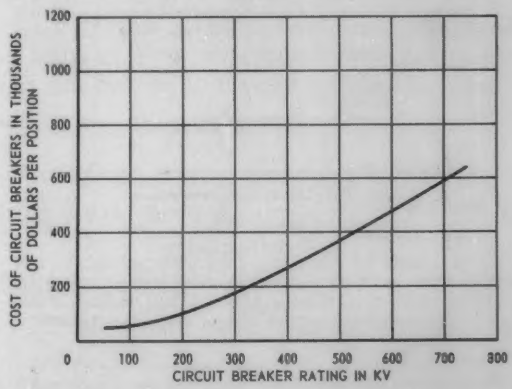
TOTAL COST of transmitting power is given by formula. **(FIGURE 2)**

factured or designed and logical multiples of these values, have been retained on the premise that cost of any intermediate voltage class cannot really be interpolated from these curves.

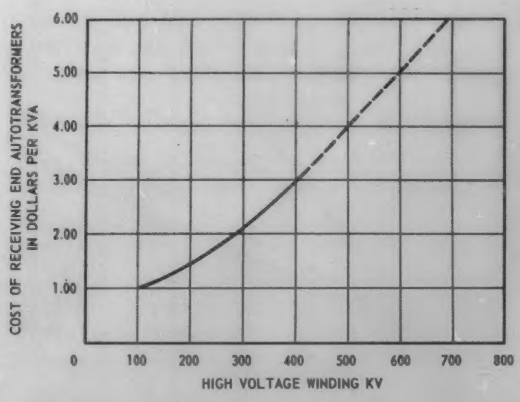
Results of such a study can be plotted in a more or less conventional manner showing relative economy of transmitting any amount of power at various voltage levels for one specific distance at a time. Figure 4 shows the results of the study plotted for a transmission distance of 400 miles. These curves indicate that with a load 400 miles away, any of the voltages shown would be the most economical one for a certain range of power requirements. If the load ranged from 320 to 1080 mw, 230 kv might well be the proper transmission voltage. If power requirements were between 1080 and 1640 mw, 345 kv would be best at a distance of 400 miles. The area between 1640 and 3250 mw could be served best by a transmission voltage of 460 kv.



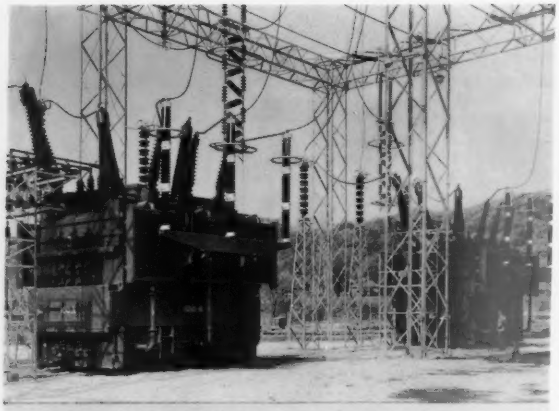
SINGLE CIRCUIT, steel-tower transmission line cost is given for various transmission voltages. Above 230 kv, study assumes use of dual conductors per phase. **(FIGURE 3a)**



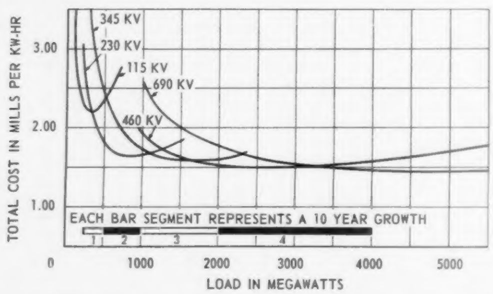
CIRCUIT BREAKER installed cost per position is given in relation to breaker kv rating. Prices refer to highest interrupting capacity available for each kv rating. **(FIGURE 3b)**



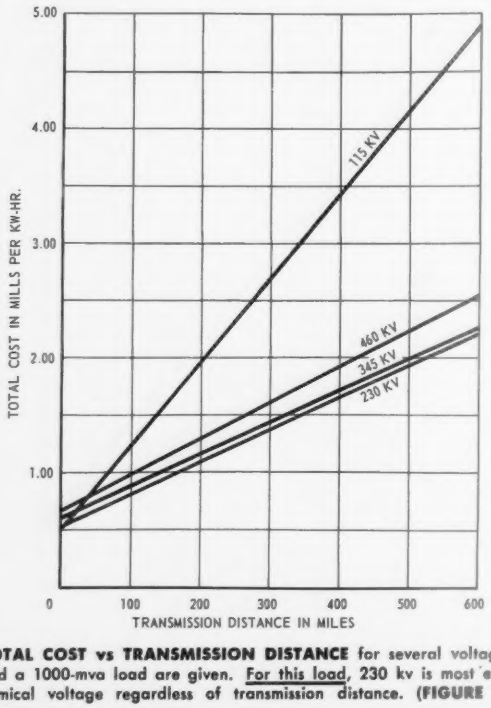
RECEIVING END AUTOTRANSFORMER cost with relation to high voltage winding kv is given. A similar graph has been developed for two winding transformers at the sending end. **(FIGURE 3c)**



AUTOTRANSFORMERS operating on first 345-kv transmission system in United States are used for sleet melting and interconnection tie service. They are rated 125,000 kva.



TOTAL COST vs LOAD is given for several voltage ratings and a 400 mile transmission distance. Bars show how doubling of load each decade will affect various voltage economies. **(FIGURE 4)**



TOTAL COST vs TRANSMISSION DISTANCE for several voltages and a 1000-mva load are given. For this load, 230 kv is most economical voltage regardless of transmission distance. **(FIGURE 5)**

The bars at the bottom of the curve are for the purpose of introducing the element of time. With a load growth of 100 percent every 10 years, each bar, plotted between appropriate limits of load in megawatts represents a 10 year span. As a specific example, the third bar says that if load to be served is presently 1000 mw and the system is operating at 230 kv, transmitting power for a distance of 400 miles, the utility is operating almost as economically as possible. The exception is that in 10 years it will not be operating economically unless system voltage has been increased to possibly 460 kv. It is interesting to note also that 345 kv will be economical as a transmission voltage for less than 10 years at the present load growth rate.

Distance variable can be removed

Because it is easier to forecast future load growth than it is to foresee the distance from a plant site to the area of load concentration, it is desirable to represent these results in a more useful manner.

To eliminate load as an independent variable rather than transmission distance, another set of curves were plotted. Each set is now for a specific value of load with the variables of cost, distance, and voltage plotted for that specific value of load. Now we may forecast power requirements of a certain area, select the most advantageous generating site, calculate the mean distance from plant site to area served and then determine from the curve to tell us what might be a good transmission voltage. Figure 5 is such a plot for 1000 mw, and the answer that it gives is that 230 kv is the most economical approach regardless of distance transmitted for the load.

Experience is a factor, too

Thus, it seems practical to consider a mine-mouth generating location even if long transmission distances are involved, when serving a major load area. By increasing voltage, more power can be transmitted over a longer distance. With the help of a set of resultant curves, such as Figure 5, it can be shown that it costs no more to transmit 200 mw over a distance of 530 miles at 460 kv than it does to transmit 100 mw of power 165 miles at 115 kv.

In this manner, given either a known load or a known transmission distance, an optimum transmission voltage can be selected. It cannot be stressed too heavily, however, that this knowledge must be tempered with experience and compared with the practical limits of each individual system. ◆

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RELAYING WITH RESIDUAL CIRCUIT RELAYS

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False tripping with residual relaying may be result of dc saturation of CT's. Here is an analysis of this problem.

WHEN A SYSTEM DISTURBANCE such as motor starting or a more severe three-phase short circuit occurs, current variations that result are asymmetrical in form. The dc component in this current will pass through current transformers on the power system. These current transformers can become saturated by the dc current and thus temporarily prevent faithful reproduction in the secondary output. If the CT's are used in conjunction with residual circuit relaying false relay operation can occur. An analysis of the nature of dc saturation may be made with basic equations.

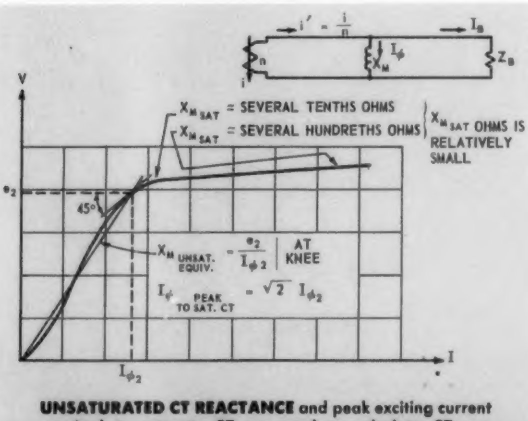
The terms used in CT saturation analysis are given in Figures 1 and 3. When burden is all resistance, the current impedance ratio relating the exciting current to the primary current referred to the secondary side of the CT and given in an operational form is as follows:

$$I\phi = \frac{R_B}{R_B + pM}\, i' = \left(\frac{R_B}{M}\right)\frac{1}{p + \frac{R_B}{M}}\, i' \text{ where } p \equiv \frac{d}{dt} \quad (1)$$

The ac current through the CT can best be handled graphically once the effect of the dc current on CT saturation is established, thus i' will be represented as dc component only. Also the ac component in the magnetizing branch is negligible in the unsaturated state.

$$I\phi = \frac{\beta}{p+\beta} I_{PEAK}\, e^{-at} = I_{PEAK}\left(\frac{\beta}{\beta - a}\right)\left(e^{-at} - e^{-\beta t}\right) \quad (2)$$

$$\text{where } \beta = \left(\frac{377}{(X_M/R_B)}\right) \text{ and } a = \left(\frac{377}{(X/R)_{Sys.}}\right)$$



UNSATURATED CT REACTANCE and peak exciting current required to saturate CT are used to calculate CT secondary current during dc transient period. (FIGURE 1)

At the first instant of fault, the CT excitation reactance is unsaturated and thus the unsaturated value of X_M is used. The excitation current $I\phi$ during the initial unsaturated state derived from Eq. 2 is as follows:

Since X_M unsaturated is large,

$$\beta = \left(\frac{377}{(X_M/R_B)}\right) \text{ is very small and } e^{-\beta t} \rightarrow 1$$

$$I\phi = I_{PEAK}\left[\left(\frac{1}{\frac{X_M/R_B}{X/R_{Sys.}} - 1}\right)\left(1 - e^{-\frac{2\pi t^{CYCLES}}{(X/R)_{Sys.}}}\right)\right] \quad (3)$$

Eq. 3 can be expressed in terms of time for CT to saturate as follows:

$$t^{CYCLES}_{SAT} = \left[-\frac{(X/R)_{Sys.}}{2\pi}\ln\left(1 - \frac{I\phi_{SAT}\left(\frac{X_M/R_B}{(X/R)_{Sys.}} - 1\right)}{I_{PEAK}}\right)\right] \quad (4)$$

The values of X_M and $I\phi_{SAT}$ can be obtained from Figure 2.

After that the time to saturate the CT is established, the duration of the dc saturated state is considered.

From Eq. 2 we can see that when the CT is saturated and X_M is small (the exact figure is unimportant). The β $-\beta t$ term becomes large thus $e \rightarrow 0$ even for the smallest times and $\left(\frac{\beta}{\beta - a}\right) \rightarrow \frac{\beta}{\beta} = 1$.

Therefore Eq. 2 can be expressed as follows during the saturated state:

$$I\phi = I_{PEAK}\, e^{-\frac{2\pi}{(X/R)_{Sys.}} t^{CYCLES}} \quad (5)$$

Eq. 5 can be expressed in terms of time for CT to unsaturate as follows:

$$t^{CYCLES}_{UNSAT} = \left[-\frac{(X/R)_{Sys.}}{2\pi}\ln\left(\frac{I\phi_{SAT}}{I_{PEAK}}\right)\right] \quad (6)$$

From Eq. 6 we can clearly see that the duration of the false currents depends primarily on the power system (X/R) and not in the (X/R) of the CT and burden.

Calculations for duration of false trip currents

Given: CT/R = 200/5 (Bushing CT), $(X/R)_{Sys.} = 10$, i = 850 amps and $R_B = 1$ ohm.

Find: Time to saturate and unsaturate.

From CT/R: $I_{PEAK} = \frac{850 \times \sqrt{2}}{200} \times 5 = 30$ amps.

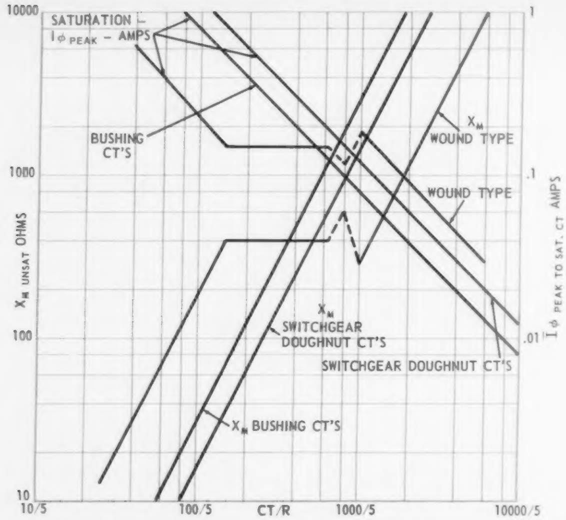
From Figure: 2: $I\phi_{SAT} = .4$; $X_M = 120\,\Omega$

From Eq. 4: $t_{SAT} = \left[-\frac{10}{2\pi}\ln\left(1 - \frac{.4\left(\frac{120}{10} - 1\right)}{30}\right)\right]$
$= 0.252$ cycles

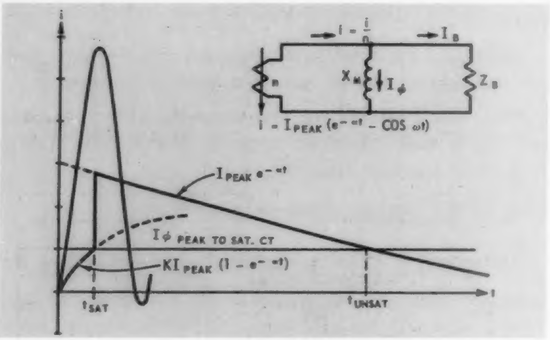
From Eq. 6: $t_{UNSAT} = \left[-\frac{10}{2\pi}\ln\left(\frac{.4}{30}\right)\right]$
$= 6.87$ cycles

The results are plotted in Figure 4-b.

When the ac current goes below the dc current and unsaturates the CT, the ac current flows into the secondary burden until saturation once more takes place during the upswing of the ac current. The area above the zero reference line equals the area below the zero line.[1]



CT EXCITING REACTANCE and current for calculations. (FIG. 2)



EQUATIONS graphically represented for clarification. (FIG. 3)

Figures 4a, 4b and 4c illustrate the effect primary current magnitude has on the secondary current. Figure 5 compared with Figure 4b illustrates the effect of system (X/R) on the secondary current.

Figure 6 shows that the effect of the dc component can take place many cycles after the initial disturbance in the primary circuit. Equations representing the effect of dc current to CT's when inductance is present in the burden take essentially the same form as the equations for all resistance burdens.

Figure 7 is an example of the secondary current of the burden when the burden is partly inductive and partly resistive. The area relationship remains although the current will not drop instantaneously to zero when the CT saturates as was the case for an all resistive burden.

Figure 8 depicts the resultant current in the residual circuit when there is a three-phase fault and phase A is symmetrical and phases B and C are asymmetrical. Phase A current flows undistorted. Phase B and C currents flow into the burden as shown by the shaded regions in Figure 8a. The addition of A, B and C are zero when all currents are flowing to the burden but when B and C currents are lost to saturation the resultant residual current will appear as Figure 8b when residual circuit impedance is zero.

Protection against dc component

There are two methods that can be used to prevent false operation of residual connected relays.

Method 1: In the following example of residual ground relaying, an instantaneous relay with external resistance is used, as shown in Figure 9.

1. Calculating magnitude of residual circuit resistor to prevent false tripping during 3 phase short circuit.

$$R_B = \frac{(i_1 - I_B)R_S}{I_B} = \left(\frac{(230 - 0.5)\,0.08}{0.5}\right) = 52.8 \text{ ohms}$$

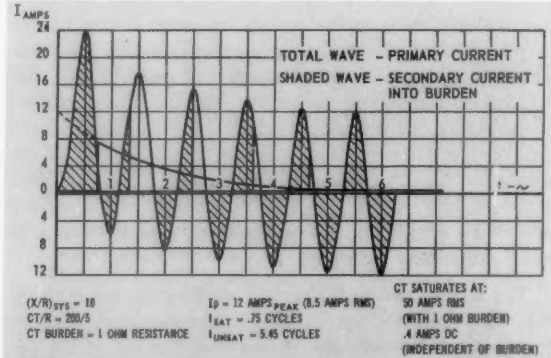
$$R_D = (R_B - R) = (52.8 - 2) = 50.8 \text{ ohms}$$

2. Checking if scheme will work for true residual current;

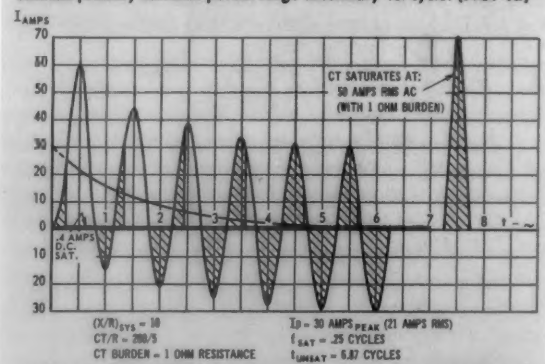
$$V_{REQUIRED} = 52.8 \times 1.0 = 52.8 \text{ volts}$$

$V_{MAX\ AVAILABLE} = 70$ volts for bushing CT, 300/5. From Figured 2, $I\phi \times X_M = 0.26 \times 270 = 70$.

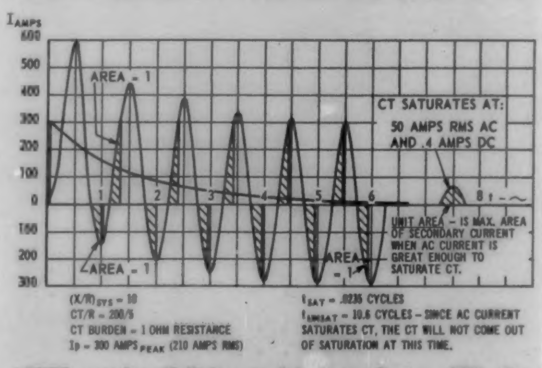
This scheme will work since it will not trip falsely during a 3ϕ disturbance, and will operate for a line-to-ground fault. However, the relay might not operate immediately, since the CT experiencing the line-to-ground short circuit could have an asymmetrical current preventing the relay from seeing any ground current immediately. The buildup of secondary relay current will depend on the power system X/R.



SMALL primary currents permit large secondary 1st cycle. (FIG. 4a)



PRIMARY CURRENTS for typical motor starting. (FIGURE 4b)



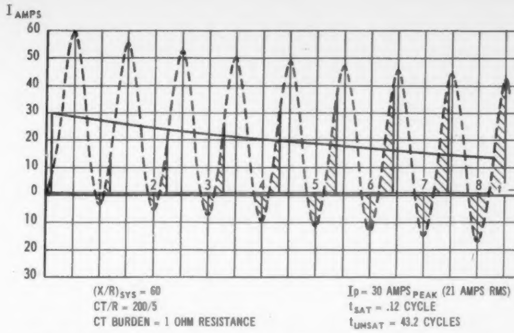
LARGE secondary IR limits secondary in steady state. (FIG. 4c)

Method 2: A time delay relay can be used to prevent false trip because it can be set on a high enough time lever to override the false currents resulting from dc transients during three-phase disturbance and yet will operate on time delay for line-to-ground short circuits.

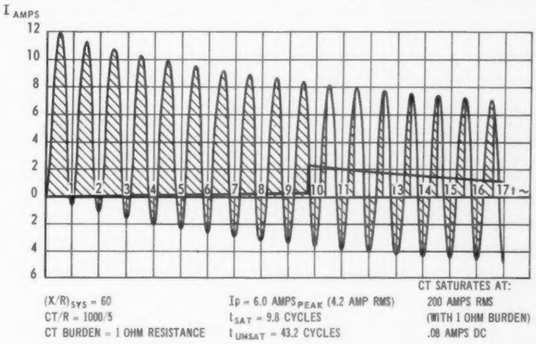
Where the power system X/R is low, the time relay should prove to be very satisfactory. However, where the power system X/R is large, the time delay involved might become prohibitively long and thus an instantaneous relay with external resistance might be required. If the system is resistance grounded to limit the ground current to approximately 1000 amps the X/R of a line-to-ground fault is so low, about $(2X/3R_N) \approx 0.05$, that the dc components are nonexistent for all practical purposes during a line-to-ground fault. However, a time delay is still necessary to prevent false tripping during a three-phase fault. Line-to-line faults tend to have cancelling phase effects so that if the three-phase fault conditions are considered the line-to-line fault will present no problems.

From analysis the following conclusion can be made:

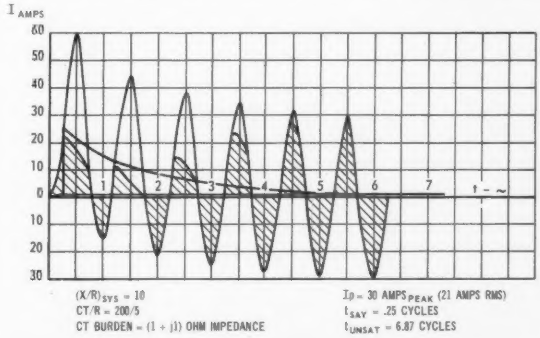
1. The first cycle of secondary burden current can be large or small depending on the primary current magnitude.
2. The duration of the saturation can be long or short depending on the power system (X/R).
3. The dc component effect on the CT secondary current is very similar for resistive and inductive burdens except that the current will not fall off immediately upon saturation during each cycle.
4. CT's with large ratios are just as susceptible to dc component saturation as CT's with small ratios.
5. Residual relay circuits can be made to perform successfully with a time relay or by adding resistance in the residual circuit to shunt the current through the two saturated CT's, and by using large enough CT's so that steady state voltage of the unsaturated CT is adequate to trip an instantaneous relay when true residual current flows.
6. A single doughnut CT with the three-phases through it provides the most reliable and sensitive relaying for line-to-ground faults because with this arrangement the dc components cancel each other as do the ac components and CT ratio can be less than rated current. ◆



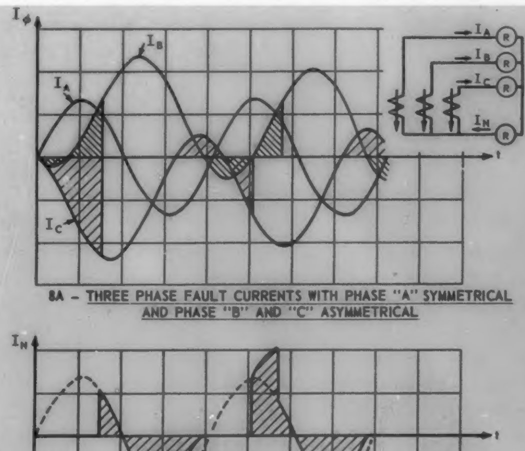
LARGE X/R ratios produce long secondary transients. (FIG. 5)



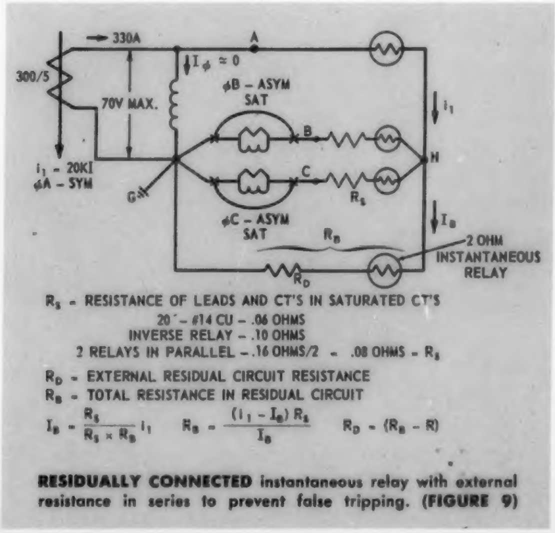
EVEN HIGH RATIO CT's with low secondary IR are affected by dc component in high X/R power systems. (FIGURE 6)



SECONDARY CURRENTS will follow essentially the same response with CT's having inductive and resistance burden as with only resistance but will not drop to zero. (FIGURE 7)

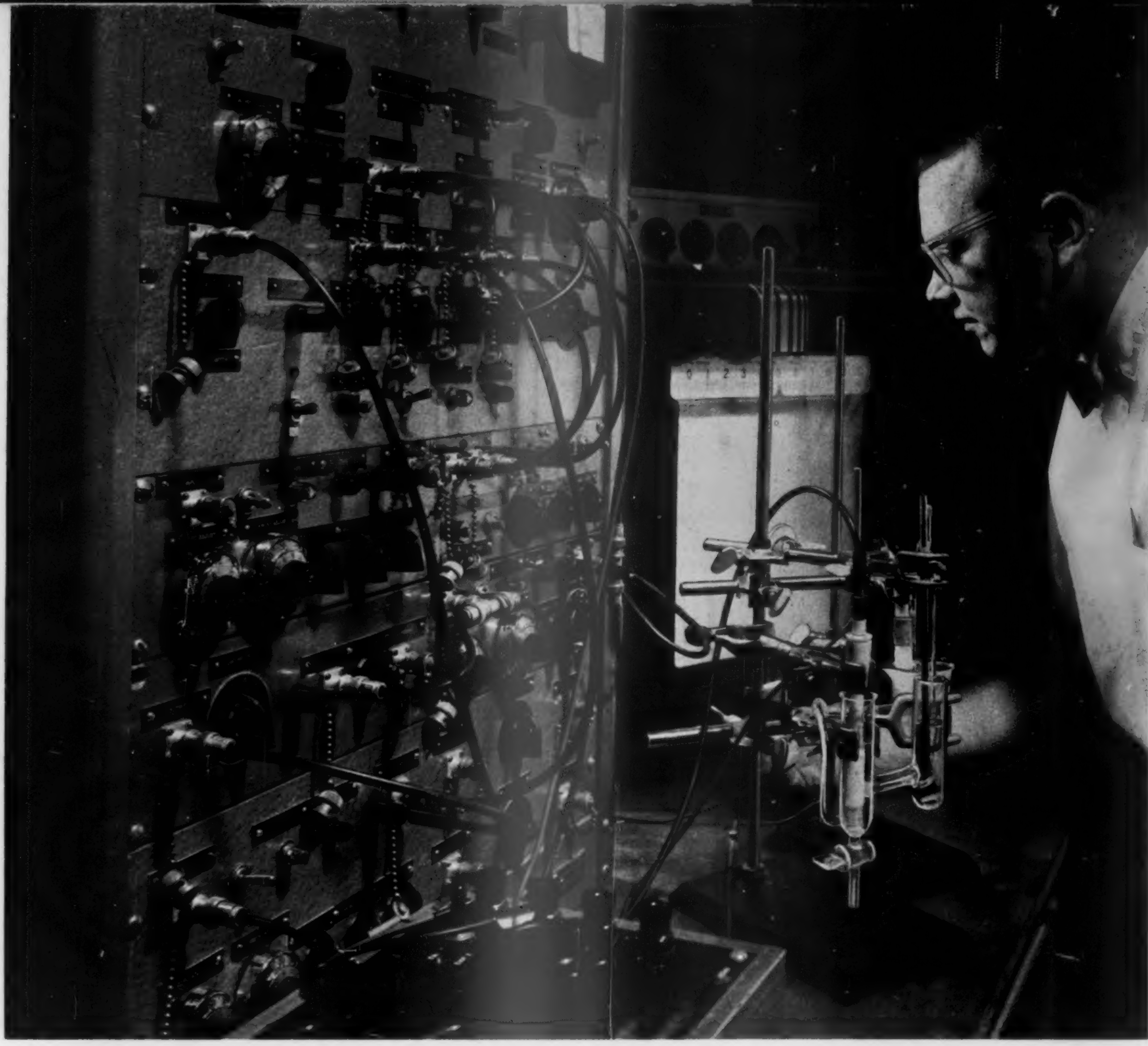


OVERCURRENT RELAYS residually connected will operate falsely unless time delay or desensitization are employed. (FIGURE 8)



RESIDUALLY CONNECTED instantaneous relay with external resistance in series to prevent false tripping. (FIGURE 9)

[1] *Protective Current Transformers and Circuits,* P. Mathews, McMillan Co., New York, N. Y. 1955



New Depth in Fuel Cell Research

FUEL CELLS HAVE DEVELOPED from laboratory curiosities used to operate 40 watt bulbs a few years ago to much more compact power sources today. Cells have operated for relatively long periods under load, and military and space agencies now plan to use them in some of their advanced experiments. As the practical design and operation improves, the fundamental research program necessarily becomes more refined and involved.

Fuel cell reactions which appear to be basically simple from the overall reaction are usually found to be much more complex in reality. The reactions usually occur in steps, one or more of which may be significantly slower than the others. It is, therefore, essential to understand the mechanism of the reactions to find the slow steps. Once the slow steps in the reactions are known, reasonable goals for catalyst selection can be set.

In addition to the major electron transfer process, many additional phenomena are possible, e.g. chemical reactions preceding or following the electron transfer steps, side reactions involving different numbers of electrons per mole of reactant than the major reaction, parasitic chemical side reactions, the formation of stable intermediates on the electrode surface, and poisoning of the electrode by impurities.

Since fuel cells must operate for long periods without maintenance, it is essential that the processes be well understood so that all parasitic, poisoning and deleterious side reactions are eliminated or controlled. To accomplish this end the studies of reaction mechanisms are essential.

Electrode reaction kinetics must be studied under well controlled conditions. To control the variables involved in electrode reactions, precision electronic equipment is required. With the development of computer electronics suitable amplifiers have become available for this purpose.

The electronic voltammetric apparatus in the accompanying photograph is such an instrument. It is precise, rapid and versatile in that it can be used to obtain constant potentials, constant currents, linearly varying potentials or with suitable signal generators, various voltage wave forms. This instrument thus permits the use by researchers of the best available methods for the study of fuel cell processes.

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